PREFACE

Medical Image registration is considered as one of the most challenging, complex and complicated tasks, while it is a key enabling technology in the field of medical images analysis. A registration algorithm (both rigid and deformable) adds values to the images of different modalities by precisely aligning them to a single coordinate system for further viewing and analysis for the applications like diagnosis of a tumour, image-guided surgery, image-guided radiotherapy, etc. Since the abdominal portion undergoes several involuntary motions (e.g. organ deformation, patient motion, movements of gastrointestinal tract or breathing), the captured images include local and global non- rigid deformations which are not always possible to compensate with rigid registration algorithms. Hence, to achieve precise alignment of the images, deformable registration is definitely required.

The characteristics of multimodal images differ, which lead towards the intensity mismatch for any particular region of interest and increases the complexity of the task of estimating relationship between corresponding pixels'. The uncertainty in the presence/ observance of structures in the abdominal images as well as the unpredictability in their appearance (size, shape) also arises major difficulties for deformable registration (intra patient/ inter patient, monomodal/ multimodal). Standard similarity measure-based deformable registrations are employed by iteratively minimizing a cost function and optimizing transformation parameters. While the outcomes of these methods are promising, these processes are computationally very demanding. To overcome the issue, learning-based frameworks are introduced, which able to register a new pair of images within (fractions of) seconds only, after a computationally intensive learning on large training datasets. This thesis contributes to the necessary theory and implementations for conventional as well as learning based deformable registration of abdominal images by generating optimal deformation fields, utilizing the information present in the images that best aligns the structures of interest.

In the first phase of the work, the conventional approach is utilized to perform deformable registration of multimodal abdominal images (Ultrasound and Computed Tomography). The proposed methodology includes segmentation of liver surface, followed by the selection of best matched CT slice from a set of CT images, calculation of objective function and finally the estimation of transformation. The gradient orientation of the pixels is calculated and included in the entropy-based objective function. Another global spatial function is also introduced to overcome the false global minimum problem. The transformation estimation is done using B-splines and Free Form Deformation (FFD), while gradient descent optimization is employed. A distance based metric is adopted for validation which performs the measurement on the basis of anatomical features points. The performance evaluation indicates that the registration method is suitable for clinical applications.

The abovementioned methodology is further utilized for registration refinement in the next phase of the thesis. This research work exhibits the implementation and evaluation of the performances of two non-rigid registration algorithms integrated with registration refinement. Along with that, three separate optimization techniques (Steepest Gradient Descent, quasi-Newton and Levenberg-Marquardt method.) are employed in the process. The first algorithm includes the multi-resolution approach. Combination of normalized mutual information with a weighted regularization term is utilized as the cost function while locally controlled B-spline with FFD is employed for the local motion modelling. The second algorithm is based on the idea of step by step increment of the registration complexity. In the primary step, the transformation estimation is performed using the similar approach of employing normalized mutual information. While in the advance step, the cost function designed previously with the gradient orientation information is utilized for the registration refinement. Both the algorithms are tested for the registration of US and CT images, and the distance based measure is used for performance evaluation. Also precision of the optimization methods is evaluated. Quantitative analysis indicates the superiority of the second algorithm and the Levenberg-Marquardt method is found to be more precise that the rest two optimizations used.

In this phase of the thesis, an unsupervised learning-based approach (VoxelMorph) is employed for deformable registration of monomodal abdominal CT images. The architecture is similar to U-Net, and it learns the complex mapping between every couple of 2D or 3D images, while utilising the spatial transformer network (STN) for generating the final image. It basically computes a generalized registration function instead of computing it every time for an image pair, hence bypassing the need of expensive optimization. For the learning of the network, a stochastic gradient descent based optimization is employed. The cost function consists of a similarity metric and a weighted regularization term. This method is tested on 2D and 3D abdominal CT images of LiTS and 3D-IRCADb-01 dataset, while only images from LiTS dataset are utilized for the learning of the network. Three different experiments are performed: 2D atlas-based, 2D pairwise, and 3D pairwise registration and validation is done using the Dice Score and Hausdorff Distance metric. Performance evaluation shows competitive outcomes with a significant improvement in computation time while comparing with the state-of-the-art conventional registration method The work also investigates the influence of the regularisation weighting parameter on the quality of registration. This approach paves the way for the routine use of deformable registration in the clinical workflow and will facilitate the development of high throughput image processing services.

To summarize, in order to develop non-rigid registration algorithm for abdominal images, the present thesis has put to use the distinguishable intensity and gradient measures of the liver for the optimal modelling of the deformation. Also, the effectiveness and convenience of using unsupervised learning-based approaches is presented in the thesis, as the employed CNN based model is able to perform deformable registration with state-of-the-art accuracy on abdominal images, while reducing the computation time.