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Title(English)	Non-Rigid Image Registration for Inter-Color Alignment and Flexible Mosaicing
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Image registration is the process of aligning the coordinate system of images and mapping them into a single image plane. This technique is used for many applications in various fields, e.g. medical imaging, cartography, and robotics. Performing image registration for general purposes often requires high dimensional image deformation models because the images must be significantly deformed in order to register into a single image. We refer to image registration using high dimensional deformation models as "non-rigid registration." As is the case with most computer-science problems, dealing with the computation in high dimensional spaces leads to difficulties on *accuracy and efficiency*. In this dissertation, we tackle these essential problems in two different topics by using two different approaches. First, we aim at performing *accurate* registration of misaligned color channel images captured asynchronously. A practical example of such a registration problem is the inter-color alignment of time-sampled endoscopic images for medical imaging applications which requires high accuracy of the registration. Second, we aim at the *efficient* registration for mosaicing of images captured under flexible photographing, i.e. we use the images captured under non-restricted camera motion w.r.t. scenes. In this topic, we focus on efficient mosaicing. We compose the registered images and produce high quality mosaics in real time. The organization of our dissertation is described below.

Chapter 1 of our dissertation, "*Introduction*", describes the general form of image deformation models defined by rigid and non-rigid warping functions. Then, we discuss the advantages and disadvantages of these warping functions. Next, for a given application of image registration, we explain how to choose the warping functions and design the energy (objective) functions accordingly. Moreover, we explain our objectives and contributions. First, we explain the problem of inter-color alignment of endoscopic images. We introduce our proposed energy function that fuses the joint entropy of the RGB space and the color gradient orientation. This energy function is designed to achieve high accuracy without additional computational costs. Second, we introduce the problem of non-rigid registration for mosaicing, and we explain why classical methods cannot solve it. We present our proposed warping and energy functions which can perform efficient mosaicing under flexible photographing. Our method is based on a fast non-rigid registration algorithm combined with a fast image-stitching method tailored for this problem.

Chapter 2, "*Accurate registration for inter-color alignment of time-sampled endoscopic images*", presents the method for accurately aligning endoscopic images. We first explain the details of time-sampled endoscopic imaging and introduce the challenges of performing registration. Second, we discuss the

works related to inter-color and multimodal alignment. Then we introduce warping and energy functions commonly used for this class of image registration.
For performing more accurate inter-color alignment, we propose a new energy function by fusing joint entropy and color gradient.

Chapter 3, "*Experiments on accurate registration for inter-color alignment*", shows the experimental results on the image registration of time-sampled endoscopic images. We first describe the experimental setup for image acquisition of endoscopic images and the implementation details. Then, we compare our method using the proposed energy function to the baseline method. Our results validate that the inter-color alignment, according to the proposed energy function, yields robust and precise results, comparable with the best related method analyzed in our work, with significantly reduced computational cost.

Chapter 4, "*Efficient non-rigid registration for image mosaicing under flexible photographing*", presents the proposed non-rigid registration method for creating mosaics from images captured under general situations, i.e. we do not require restrictions in either camera motions or scenes for image acquisition. The only limitation is that the warping function must not have any discontinuities. First, we introduce the related methods, followed by the scope of our proposed mosaicing systems. Second, we define the warping function by using a triangular mesh model. Third, we present an efficient non-rigid registration approach by focusing on the fact that, even though the deformation model is high dimensional, it can be sparsely represented. Also, the energy function is quadratic, and thus can be optimized efficiently. Therefore, by solving linear systems, we can find the optimum of the energy functions efficiently. In addition, for accelerating the entire process, we propose a method for selecting informative key-frames by using the statistics of feature matches. Also, we propose an efficient graph cut formulation for pixel selection specially tailored for non-rigid registration. Finally we propose a registration method capable of registering a set of images while keeping the alignment globally consistent. This method is intended to be used as post-processing.

Chapter 5, "*Experiments on efficient registration for image mosaicing*", shows the experimental results on the image registration for a set of images (both video key-frames and photos) captured under flexible photographing. We first describe the experimental setup for image/video acquisition and the implementation details. Next, for video stream inputs, we demonstrate that our proposed mosaicing method is capable of running in real-time while performing a more precise registration than related methods with rigid deformation models. In addition, we qualitatively validate that our proposed post-processing methods improve the quality of the final mosaics.

Finally, chapter 6, "*Conclusions and future work*", presents the conclnsions of this dissertation, together with some possible future venues of research. First, we discuss a possible improvement of our inter-color

alignment method. Instead of using a general optimization method, as previously done in the experiments, we could investigate better optimization methods that explore the characteristics of the proposed energy function. Second, we discuss possible extensions to our proposed mosaicing method. Our system only creates planar mosaics. We could extend the mosaic creation to other shapes, such as cylinders and spheres.