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Mosaicing of Images with Few Textures and Strong Illumination changes: Application to Gastroscopic Scenes

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Scientific challenges

- Registration of images acquired under complex conditions combining non-textured scenes with significant illumination changes between images and specular reflections.
- Mosaicing of gastroscopic image sequences: non-linear relationship between pixel positions in the 2D mosaic due to non-planar and non-static surfaces (homographies are unusable).

Contributions

1. *Efficient descriptor-based variational optical flow (OF) method* (appropriate for scenes with few textures, strong illumination changes between images and specular reflections).
2. *Proposal of a general form of illumination-invariant patch-based descriptors:* the illumination invariance is proven both theoretically and experimentally.
3. *Accurate mosaicing method:* OF fields are directly used to map the pixels from input images to the 2D mosaic coordinate system.

References

[1] D. H. Trinh, W. Blondel, and C. Daul, "A general form of illumination-invariant descriptors in variational optical flow estimation," *in IEEE Int. Conf. on Image Processing (ICIP)*, Beijing, China, Sept. 2017.

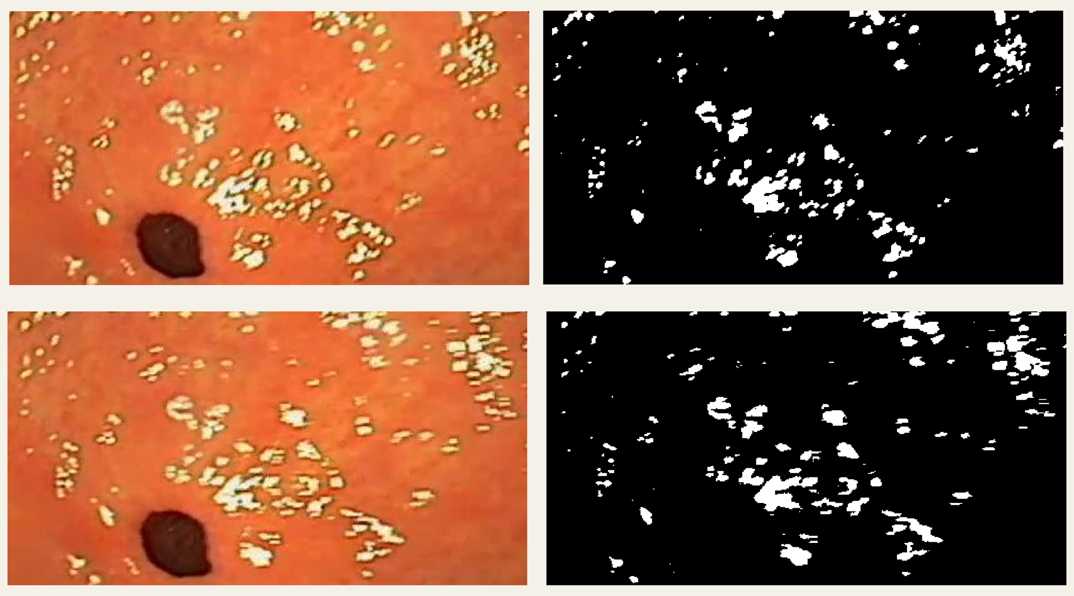
[2] S. Ali, C. Daul, E. Galbrun, and W. Blondel, "Illumination invariant optical flow using neighborhood descriptors," *Computer Vision and Image Understanding*, vol. 145, pp. 95–110, 2016.

[3] M. Drulea and S. Nedevschi, "Motion estimation using the correlation transform," *IEEE Trans. on Image Processing*, vol. 22, no. 8, pp. 3260–3270, 2013.

[4] Yinlin Hu, Rui Song, and Yunsong Li, "Efficient coarse-to-fine patch match for large displacement optical flow," in *CVPR*, Boston, MA, USA. 2016, IEEE.

[5] O. E. Meslouhi, M. Kardouchi, H. Allali, T. Gadi, and Y. A. Benkaddour, "Automatic detection and inpainting of specular reflections for colposcopic images," *Central European Journal of Computer Science*, vol. 1, no. 3, pp. 341–354, 2011.

Proposed variational OF method



Gastroscopic images affected by specular reflections (SR) and results of SR regions detection using [5]. The size and shapes of SR regions vary strongly between images.

SR detection [5]:

- $\tilde{I}_x(R,G,B) = \frac{\min(R_x,G_x,B_x)}{\max(R_x,G_x,B_x)} I_x(R,G,B)$
- $\tilde{I}(R,G,B) \xrightarrow[\text{convert RGB to XYZ}]{} I(X,Y,Z)$ and $\mathcal{Y} = \frac{Y}{X+Y+Z}$

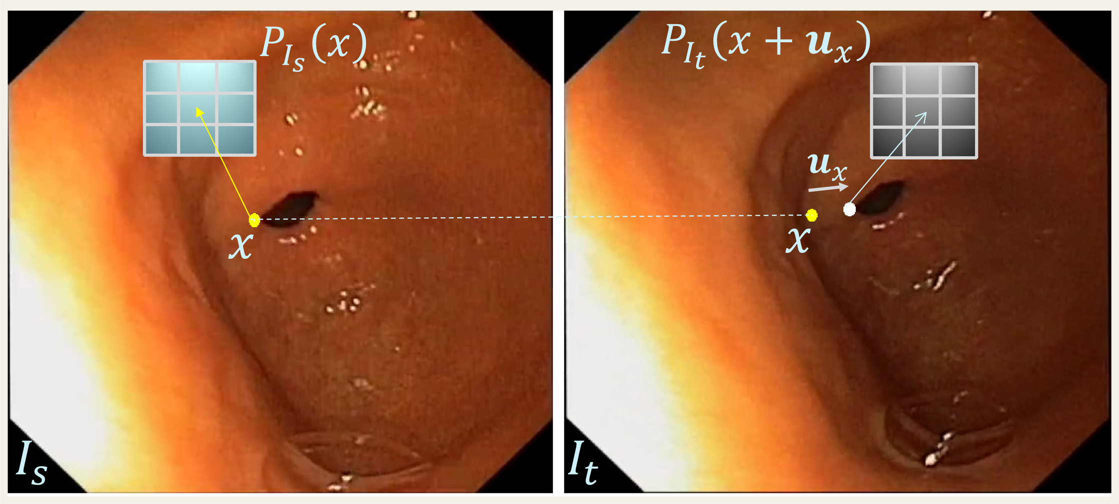
If $Y_x > \mathcal{Y}_x$ then x is considered as a SR pixel.

*Denote by $\mathcal{S}_I$ the set of detected SR pixels in an image *I*.

$$\mathcal{S} = \text{dilation}(\mathcal{S}_{I_s}, se) \cup \text{dilation}(\mathcal{S}_{I_t} e)$$

with *se* a structural element having a size of 7x7 pixels.

The pixels which belong to $\mathcal{S}$ will not be involved in the OF computation process.



Descriptor-based variational OF model:

$$\min_{\boldsymbol{u}} [E_{reg}(\boldsymbol{u}) + \lambda E_{data}(I_s, I_t, \boldsymbol{u})] \quad (1)$$

where

$$E_{reg}(\boldsymbol{u}) = \sum_{x\in\Omega} \sum_{x'\in\mathcal{N}_x} \theta_x \theta_{x'} w_x^{x'} \|\boldsymbol{u}_x - \boldsymbol{u}_{x'}\|_1, \quad (2)$$

with

$$w_x^{x'} = \exp\left(\frac{-\|x-x'\|_2^2}{2\sigma_1^2} + \frac{-\|L(x)-L(x')\|_2^2}{2\sigma_2^2}\right), \quad (3)$$

$$\theta_x = \begin{cases} 0 \text{ if } x \in \mathcal{S} \\ 1 \text{ if } x \notin \mathcal{S} \end{cases}, \quad (4)$$

and

$$E_{data}(I_s, I_t, \boldsymbol{u}) = \sum_{x\in\Omega} \theta_x \left\| \boldsymbol{D}\left(P_{I_s}(x)\right) - \boldsymbol{D}\left(P_{I_t}(x+\boldsymbol{u}_x)\right) \right\|_2^2.$$

Illumination-invariant descriptor

- Local/patch region illumination change model [1]

$$P_{I_t}(x+\boldsymbol{u}_x) = a_x P_{I_s}(x) + b_x \quad (5)$$

where $a_x, b_x \in \mathbb{R}$, and $a_x > 0$.

- Descriptor $\boldsymbol{D}$ is called an illumination - invariant when

$$\boldsymbol{D}(P_I(x)) = \boldsymbol{D}(a_x P_I(x) + b_x) \quad (6)$$

$$\forall a_x > 0, b_x \in \mathbb{R}.$$

General form of illumination-invariant patch-based descriptors

$$\mathbf{D}(P_I(x_0)) = \begin{bmatrix} \text{sgn}(M_1 \otimes P_I(x_0)) \\ \text{sgn}(M_2 \otimes P_I(x_0)) \\ \vdots \\ \text{sgn}(M_n \otimes P_I(x_0)) \end{bmatrix} \quad M_i = \begin{array}{|c|c|c|} \hline \alpha_{i,4} & \alpha_{i,3} & \alpha_{i,2} \\ \hline \alpha_{i,5} & \alpha_{i,0} & \alpha_{i,1} \\ \hline \alpha_{i,6} & \alpha_{i,7} & \alpha_{i,8} \\ \hline \end{array}$$

$$\alpha_{i,0} + \alpha_{i,1} + \cdots + \alpha_{i,8} = 0$$

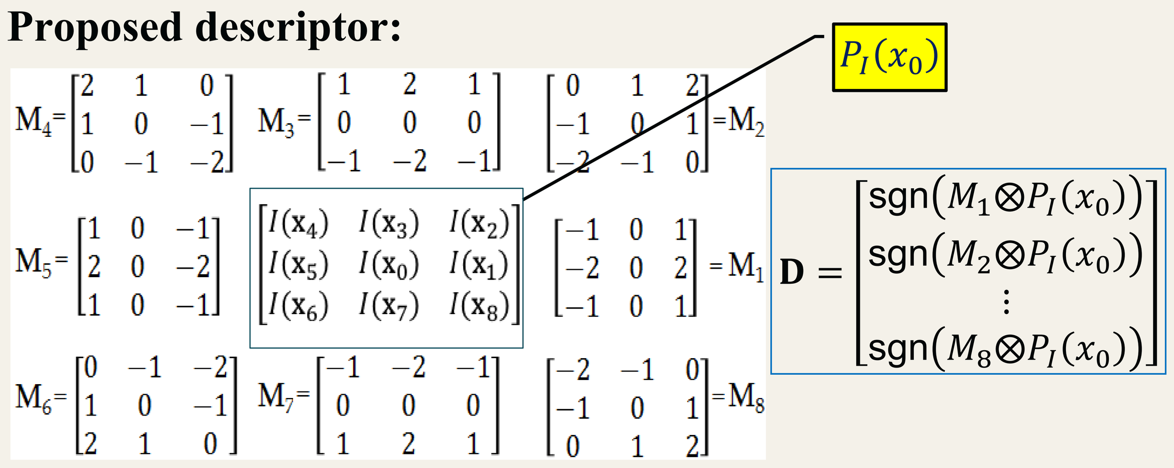
$$M_i \otimes P_I(x_0) = \sum_{j=0}^{8} \alpha_{i,j} I(x_j) \text{ and } \text{sgn}(v) = \begin{cases} 1 & \text{if } v > 0 \\ 0 & \text{otherwise} \end{cases}.$$

- $M_i \otimes (a_{x_0} P_I(x_0) + b_{x_0}) = a_{x_0} M_i \otimes P_I(x_0) + b_{x_0} \sum_{j=0}^{8} \alpha_{i,j} = a_{x_0} M_i \otimes P_I(x_0), \forall i. \quad (7)$

$$\Rightarrow \text{sgn}\left(M_i \otimes (a_{x_0} P_I(x) + b_{x_0})\right) = \text{sgn}(M_i \otimes P_I(x_0)), \forall i.$$

This descriptor satisfies illumination-invariant condition (6).

Proposed descriptor:



Robinson kernels

Endoscopic image mosaicing

Input: Image sequence: $\{I_1, I_2, \dots, I_N\} = \{I_{k_0}, I_{k_0-1}, \dots, I_1\} \cup \{I_{k_0}, I_{k_0+1}, \dots, I_N\}, k_0 = median(1,2,3,\dots,N); \boldsymbol{I}_{mosaic} = I_{k_0}$.

Step 1: Mapping of the pixels of I_n to the coordinate system of I_{k_0}

- Compute OF from I_{k_0} to I_n :

$$F_{k_0,n} = \sum_{i=k_0}^{n-1} OF_{i,i+1} \text{ if } n > k_0$$
$$F_{k_0,n} = \sum_{i=k_0}^{n+1} OF_{i,i-1} \text{ if } n < k_0. \quad (8)$$

- Perform warping I_n into the common coordinate system using $F_{k_0,n}$ and linear interpolation to get the warped image I_n^{warped}.

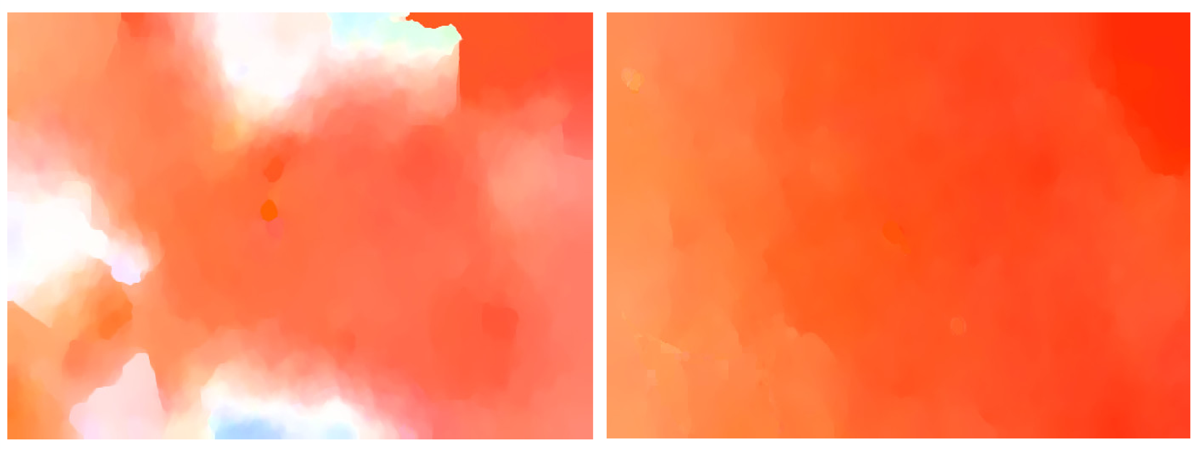
Step 2: Blending: For n = 1 to N

$$\boldsymbol{I}_{mosaic} \leftarrow \textbf{Blending}(\boldsymbol{I}_{mosaic}, I_n^{warped}); \quad (9)$$

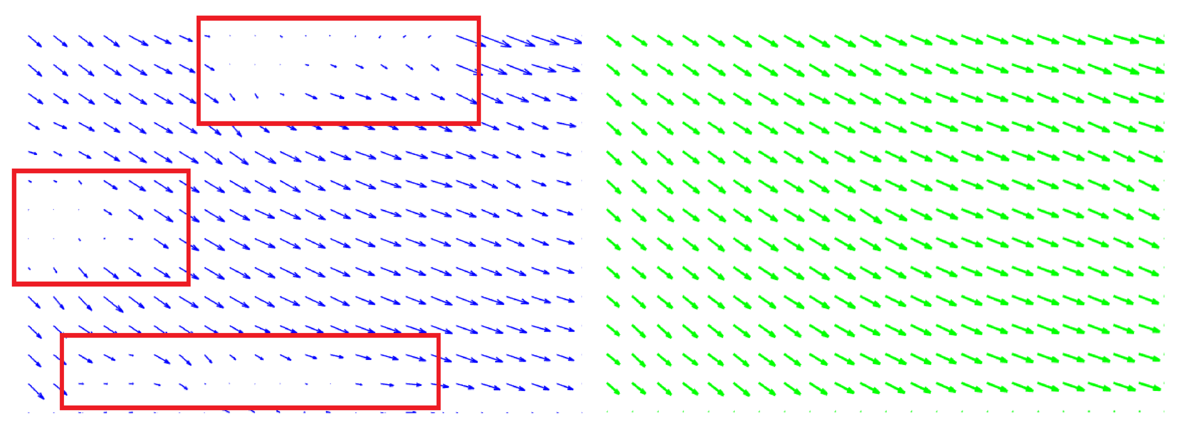
Output: $\boldsymbol{I}_{mosaic}$

Experimental Results

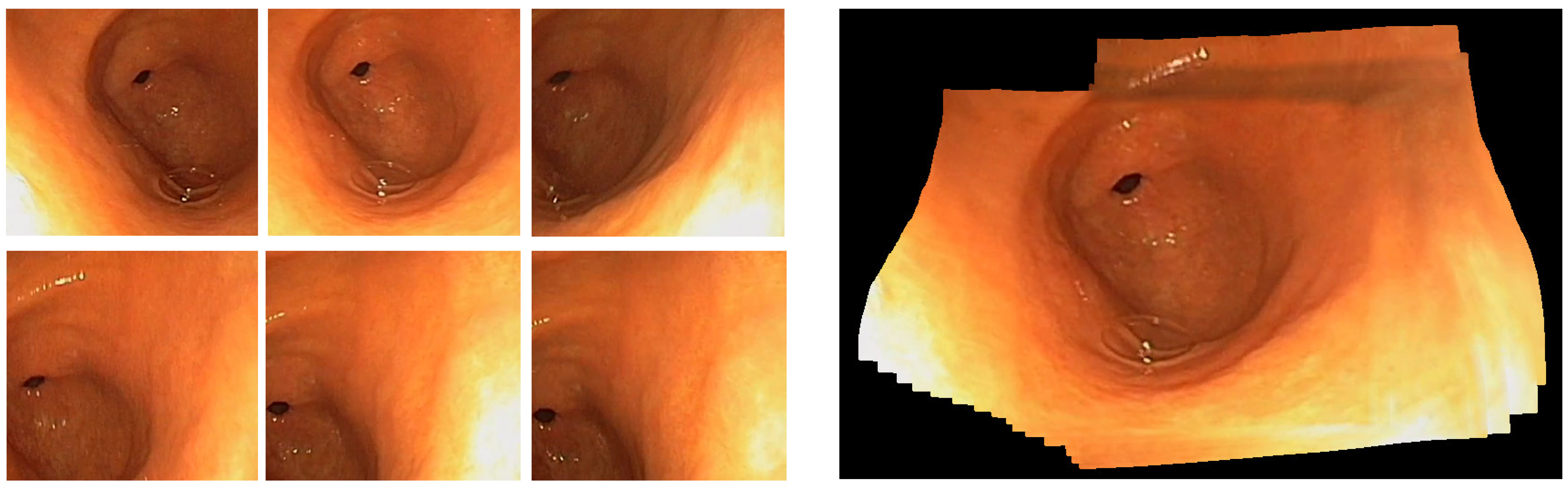
Source Image Target Image



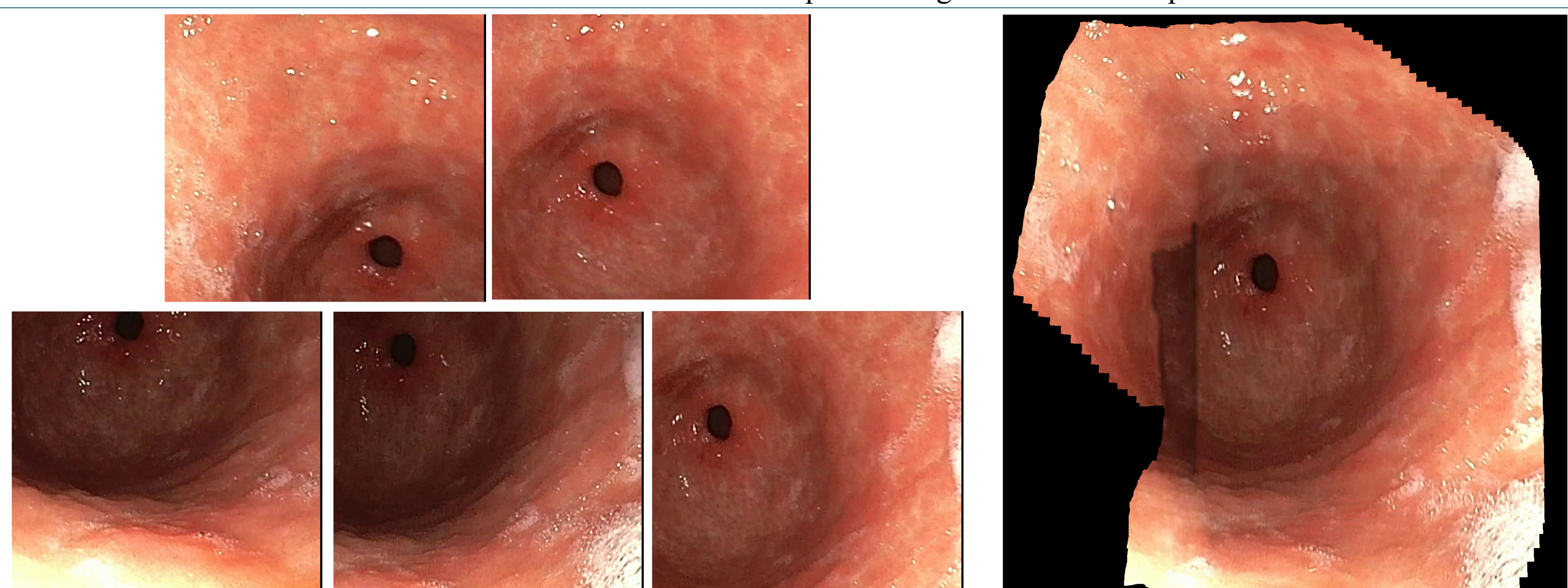
CPM-Flow [3] Proposed OF method



OF results of the CPM-Flow method [4] and the proposed OF method based on the RKII-descriptor.



Mosaic built with 22 images extracted from a gastroscopic video-sequence in the pyloric antrum region. Color discontinuities are due to viewpoint changes of the endoscope.



Mosaicing result for a gastroscopic sequence of 58 images. Color discontinuities were not corrected to show the contribution of different images to the mosaic.