

Survey of Computer Vision and Machine Learning in Gastrointestinal Endoscopy

Anant S. Vemuri

Index Terms—Computer assisted intervention, gastro-intestinal (GI) endoscopy, Barrett's Oesophagus, biopsy relocation, electromagnetic tracking, video synchronization.

This paper attempts to provide the reader a place to begin studying the application of computer vision and machine learning to gastrointestinal (GI) endoscopy. They have been classified into 18 categories. It should be noted by the reader that this is a review from pre-deep learning era. A lot of deep learning based applications have not been covered in this thesis.

I. ENDOSCOPIC APPLICATIONS

The clinical applications have been classified into the following 18 broad categories:

1) *Polyp Detection and Classification (PD)*: All colorectal cancers (CRC) develop from dysplastic precursor lesions. This is true either in the presence of a predisposing factor such as in inflammatory bowel diseases (IBD) or lack thereof, with lesions occurring sporadically. Macroscopically the shape of lesions observed in the colon have been classified as described in [1], [2]. This class of application involves first detecting the polyps visible during colonoscopy and then presenting a classification based on their type. In [3] feature descriptor using the colour and pixel position in image is used for polyp detection using SVM and in [4], that feature is compared with Colour Wavelet covariance and LBP. In [5], [6], texture features using GLCM are compared with LBP using SVM for classification. [7] proposed using edges, followed by a hough transform of the image before using GLCM for texture features detection. They employed an adaboost classifier. In [8], firstly a model is defined for polyp appearance as enclosed by intensity valleys, including specular highlights and blood vessels to make the model robust. Using this a polyp localization energy map is generated, which is then used as an input for polyp segmentation. Also refer [9]–[11] for more details. [12], presented an algorithm, termed as the Classification of Regional Feature (CoRF), that is an extension of the sparse matrix and vector quantization for feature detection and segmentation. CoRF solves the intrinsic block selection problem of vector quantization by including training codebook about the shape of regional feature. They demonstrated that this approach works better for polyp detection and segmentation, as opposed to k-means or LGB clustering.

In [13], authors evaluated the discriminative power of image features extracted from sub-bands of the Gabor and the Dual-Tree Complex Wavelet Transform for the classification of zoom-endoscopy images. Further they also incorporated colour channel information and show, that this leads to superior classification results, compared to luminance-only based processing. Later, in [14], a colour wavelet cross co-occurrence matrix is proposed and use it to obtain statistical features for classification. This new wavelet-domain based colour texture feature extends the concept of classic co-occurrence matrices to capture information between detail sub-band pairs of different colour channels. The descriptor is then used for polyp detection using a KNN classifier with Euclidean distance metric. Further work from the authors can be referred from [13]–[15]. In [16], an approach to polyp classification is presented using vessel segmentation to extract, 22 features that describe the complex vessel topologies. Three feature selection strategies are compared with Simulated Annealing giving the best performance for polyp classification. [17], proposes a new descriptor by analysing shape of the connected components (blobs). The shape is described using convex hull, skeletonization, perimeter based features and contrast feature histograms for mucosal texture classification of polyps using Pentax iScan chromoendoscopy. The readers are referred to following notable works for further incite; [18]–[46]

2) *Ulcer Detection (UD)*: Oesophageal and gastric ulcers are caused as a result of GORD. In the colon ulcerative colitis (a type of IBD) occurs when the lining of the large intestine (colon) and the rectum become inflamed. This inflammation produces tiny sores called ulcers on the lining of the colon. It usually begins in the rectum and spreads upward.

The proposed method in [47] involves decomposition of images into components called as intrinsic mode functions, using bi-dimensional ensemble empirical mode decomposition. From the decomposition, two lacunarity based colour texture characteristics were obtained; the second and higher order correlation between intrinsic texture primitives and pixel intensity distribution. An SVM classifier is used on these features for UD.

In [48], an overview of the three image decomposition approaches is provided, a) Empirical mode decomposition or EMD ; b) Ensemble EMD and; c) Bidimensional EEMD , that provide the intrinsic mode functions (IMF). A differential Lacunarity (DLac) metric is computed at each IMF and the responses matched with the characteristics of an ulcerated image. Those IMFs that are closely

related to the diseased condition are selected for reconstruction of the decomposed image. The DLac response vector computed earlier is used as the feature vector. Using this descriptor, classifier performance comparison between LDA, Quadratic discriminant analysis, NN using Mahalanobis distance and SVM was performed. In [49], on the other hand, authors use the lacunarity based colour texture features were used to investigate how the structural information of healthy and abnormal tissue is distributed on RGB, HSV and CIE Lab colour spaces.

In [50], an HSV colour space feature histogram was used along with texture features extracted using the Contourlet transform and the Log Gabor filter, which were used to train an SVM classifier for UD. In [51], a curvelet based local binary pattern is proposed for texture feature extraction, to distinguish ulcer from normal regions, by training a multilayer perceptron neural network classifier. Readers are referred to the following references; [28], [52], [52]–[61]

- 3) *Celiac Disease Detection (CED)*: Celiac disease is an autoimmune disorder that can occur in genetically predisposed people where the ingestion of gluten leads to damage in the small intestine. During the course of Celiac disease, the mucosa loses its absorptive villi, leading to a strongly diminished ability to absorb nutrients. The gold standard for detection is based on extraction of biopsies from suspicious regions, which are identified during duodenoscopy using different imaging modalities. Computer aided detection methods to automatically mark suspicious regions during endoscopy have been widely explored in literature to decrease the miss-rates.

[62], presents a CED approach by providing a comparison of classification between LBP, LTP, Multi-Fractal Spectrum, Dual-Tree Complex Wavelet Transform, Shape Curvature Histogram, Fisher vector and Vector of Locally Aggregated descriptors using a linear SVM classifier. They also provide a comparison under NBI, HD zoom endoscopy and standard white light endoscopy. Variants of DT-CWT are explored for automatic classification of endoscopic images using the Marsh classification, in [63]. The feature vector was composed of mean and standard deviations of the sub-bands from DT-CWT variant or Weibull parameter of the sub-bands. Enhanced scale invariance was obtained by applying DFT or DCT across the scale dimension of the feature vector. A k -NN classifier was used with leave-one-out cross-validation. In [64], [65], spatial domain (histogram) and transform domain (wavelet or Fourier) features are extracted from the images. A comparison between k -NN, SVM and bayes classifier is presented. The following references provide further details; [66]–[79].

- 4) *Crohn's Disease Detection (CRD)*: This is another kind of IBD, sometimes attributed to the aggressive immune response to harmless bacteria, by causing inflammation (normal immune system response), leading to chronic inflammation, ulceration, thickening of the intestinal wall, and eventually causing patient symptoms. CRD can occur anywhere from the mouth to the anus but most commonly

observed in the ileum and beginning of the colon. [80], introduces a generic image matching methodology in presence of a complex scene by combining the output of multiple matchers using a single decision function. They provide a study on improving the SVM classifier performance under this framework. [81] provides the framework for lesion segmentation with application to Crohn's disease.

- 5) *Haemorrhoid and Bleeding Detection (HD and BD)*: Haemorrhoids are itching, painful or bleeding masses of swollen tissues and veins located in the anus and rectum. Bleeding on the other hand could be attributed to wide variety of reasons such as, Angiodysplasia (abnormalities in the blood vessels near the intestines), polyps, ulcers, Crohn's disease, colon cancer, including haemorrhoids. Detection of bleeding thus is very important as it usually indicates a severe condition in the lumen.

[82], use a descriptor comprising of the HSV histogram, dominant colour and texture features from the colour co-occurrence matrix. The dominant colour feature vector included, 8 representative colours, their variances and their percentages in the image. They propose a down-sampling strategy based on unsupervised clustering and probability driven sampling from each cluster to preserve the geometric structure while using fewer instances to train an ensemble of SVM classifiers. [53] present a study of all the MPEG-7 descriptors to determine the ones best suited for BD, UD and PD. Experiments indicated that the best results were obtained when using scalable colour and homogeneous texture descriptors, especially when only relevant coefficients are used using PCA. In [83], [84], an ANN classifier was trained using, texture features were extracted in RGB and HSV spaces. An alternate approach was proposed using CIE-LAB colour space with image covariance weighting. [85] introduced a clipped illumination invariant colour space, to compute an alternate binary feature vector, as opposed to the conventional colour histogram, by comparing similarity between local histograms instead of checking for the existence of a specified pattern. An SVM classifier is trained using this binary feature vector. In [86], pixels are grouped through a super-pixel segmentation and, for each super-pixel, the red ratio in RGB space is used as a feature descriptor, which is used to train an SVM classifier. [87] employed the statistical texture descriptors in the hue space to train a k -NN classifier. [88] defined an intrinsic colour model using YIO was proposed. This was used to extract statistical features to train an SVM classifier for BD. For further reading, please refer to the following references; HD - [89], [90] and BD - [56]–[58], [60], [91]–[107]

- 6) *Oesophageal tissue Analysis (OA)*: There are two main types of oesophageal cancers; squamous cell cancer and oesophageal adenocarcinoma (OAC). Squamous cell cancer occurs most commonly in people who smoke cigarettes and drink alcohol excessively. Whereas, OAC occurs most commonly in people with gastro-oesophageal reflux disease (GORD). The latter condition has seen an

increase in frequency in the last two decades. GORD, a benign complication caused when the stomach acid escapes into the lower part of the oesophagus. As a chronic condition, it leads to changes in the oesophageal lining, causing the tissue to resemble the intestinal wall. This pathological condition is termed as Barrett's oesophagus (BO). Several studies have indicated a direct link of BO with OAC. OAC appears to arise from the Barrett's mucosa through progressive degrees of dysplasia [108], [109] observed in the cells of the lower oesophagus. The possibility of being able to perform staging of the precancerous tissue, provides room for early diagnosis and targeted treatments, avoiding emergency surgical interventions such as oesophagectomy.

The literature reviews methods that include computer-aided detection of these conditions to aide diagnosis. [110] propose using heterogeneous descriptors computed from heterogeneous colour spaces. Instead of concatenating the descriptors to a super vector, a hierarchical heterogeneous descriptor SVM framework is proposed to simultaneously apply heterogeneous descriptors for GORD diagnosis and overcome the curse of dimensionality problem. [111] proposed a content-based image retrieval framework for detection of precancerous lesions in the oesophagus based on colour-texture analysis. The novelty of their approach lies in the interactive loop provided by a relevance feedback algorithm to improve detection accuracy. [112], presented a comparative evaluation of SVM, K-NN and boosting for detection of OA under NBI, WL and chromoendoscopy. [113] propose to train an SVM classifier using local colour and texture features, from on the original and on the Gabor-filtered image. Based on the spectral characteristics of the cancerous tissue, specific filters were designed.

- 7) *Motility Detection (MD)*: It is a term used to describe contraction of the muscles that mix and propel contents in the GI tract, with each of the four regions of the GI tract exhibiting specific characteristic movements and are separated by sphincter muscles and abnormal motility or sensitivity in any part of the tract can cause characteristic symptoms [114]. In [115], Laplacian of Gaussian filter is used to extract the lumen, then sum of the lumen area throughout the sequence of 9 frames which is compared with two certain thresholds empirically set with the help of the experts. Optical flow based, ego motion estimation is performed and a Relevance-Vector-Machine classifier is used on the ego-motion representation to extract images with motility. [116] tackles the problem learning a robust classification function from a very small sample set, when a related but unlabelled data set (for MD) is provided. In [117], at the first level of the system, each video was processed resulting in a number of possible contraction sequences. To encode the patterns of intestinal motility, a panel of textural and morphological features of the intestine lumen were extracted. In the second part, the final recognition of contractions sequences was carried out by means of a SVM classifier. [118], proposes a novel method based on anisotropic image filtering and

efficient statistical classification of contraction features. In particular, the image gradient tensor was applied for mining informative skeletons from the original image and a sequence of descriptors for capturing the characteristic pattern of contractions. [119], [120] use linear radial patterns by means of the valleys and ridges detection. In this context, they propose descriptors of directional information using steerable filters. Self-organizing maps were used in general summarization for MD. Later, in [121], use textural, colour and blob features to train a classifier for MD. In [122]–[124], propose two sets of features. First, motility based features in which, contractile activity characterization is performed using valley detection through use of Gabor-like filters. Then, the valley image is converted into a 1D signal representing the valley positions. Peak detection is performed that represent contractions in valley positions signal. Second, lumen perimeter estimation is performed, by applying mean-shift clustering to reduce noise in colour distribution. Then on grayscale image, thresholding is performed to segment the lumen. Morphological operators are then used for detection of smooth regions in the intestinal lumen. A combination of, histograms of SIFT Flow Directions to describe the flow course; SIFT descriptors to represent image intestine structure and; SIFT flow magnitude to quantify intestinal deformation, was proposed in [125].

- 8) *Endoscopic Abnormality Detection and Classification (ABD)*: This is a broad category that encompasses, all the kinds of lesions or abnormalities that cannot be classified clinically, in any of the above mentioned classes. The methodologies presented here do not focus on any specific disease condition but aim to differentiate a normal tissue from abnormal one. [126] provides a review of various feature descriptors used in lesion detection in colonoscopic videos.

[127] proposed, textural analysis of the different colour channels, using the wavelet transform to select the bands containing the most significant texture information. Later, in [128], the texture descriptors from co-occurrence matrix at two different scales was used in conjunction with second and higher order moments from the GLCM computed from the image recovered using specific selected scales of the wavelet decomposition of the original image as descriptors. In [129], statistical textural descriptors were computed taken from the Discrete Curvelet transform of the image in multiple directions and scales. The covariance of texture descriptors is used as the final feature vector. [130], performed a comparison between descriptors obtained from wavelet decomposition and discrete curvelet transform. In each case an ANN classifier was trained using the described feature vector. [131] proposed using image patches in the BoW model generated using a random forest based clustering which were used to train an SVM classifier. In [132], [133], colour histogram statistics were computed for images in R,G,B,H,S,V channels of the WCE images. Additionally, a local texture information was collected for each pixel

by using a LTP and labelled as part of a texture unit. This complete information vector is used for classification using a neural network trained using the Bayesian ying-yang method to maximize entropy.

[134] used image level annotations to learn a set of online local features for adenoma detection in patches extracted in images. The BRISK based spatial structure is used for sampling pixels for learning visual descriptors. [135], proposed an extended Gaussian filtered LBP descriptor, robust to illumination changes, noise. The algorithm is claimed to be able to capture more informative edge-like features. [136] proposes a new method to choose a subset of cluster pairs based on the idea of Latent Semantic Analysis (LSA) and proposes a new inter-cluster statistics which captures richer information than the traditional co-occurrence information. In [137], authors present two schemes. The first, working on the full-resolution image, the second on a multi-scale pyramid space. With this framework any feature descriptor could be employed; but a multi-resolution LBP was tested. In [138], Root-SIFT and a multi-resolution local patterns descriptors were extracted from image patches, for each colour channel.

For complete set of references, readers are referred to the following list: [58], [59], [139]–[190]

- 9) *Endoscopic Navigation (NAV) and 6-DOF Localization (LOC)*: Navigation refers to, using the current endoscopic image information, for determining where to go next. In some ways it charts the path ahead for endoscope. Whereas, localization uses the data from previous few seconds to estimate the current pose or anatomical location of endoscope in the GI tract. This information could be in two forms; as knowledge of the section of GI tract, such as oesophagus, stomach, duodenum, ileum etc., determined by classifying the tissue structure; or secondly, by estimating the complete endoscopic motion to obtain the 6-DOF pose of the endoscope.

[191], modelled the colon as a cylinder. By estimating the camera motion parameters between each consecutive frame, circumferential bands from the cylinder of the colon surface were extracted. Registering these extracted band images from adjacent video frames provided a visibility map, that could reveal unexplored areas by clinicians from colonoscopy videos. [192] proposed, learning the pose from the optical flow fields in WCE images. Feature descriptors were generated using lumen centred and grid based methodology. ANN was used to evaluate the strength of descriptors extracted from WL and NBI images. In [193], [194], authors propose extraction of SURF features and use RANSAC based matching to estimate homography between consecutive frames to provide navigational help. [195] proposes to use lumen detection for image-guided visual servoing in endoscopy. For NAV application, the readers are invited to review the following additional references [196]–[216].

[217], [218], propose to use, MPEG-7 features along with vector quantization and PCA for descriptor compression. A neural network was trained to classify different section of the GI tract using the computed features. [219],

propose multi-scale elastic registration of consecutive frames of the WCE and extraction of projective geometry to determine the pose of the capsule endoscope. [220] employed Gabor filter based texture descriptors to detect duodenum in WCE video stream. For [221], the paper proposes a roll angle estimation for complete 6-DOF pose recovery. [222] proposes a hybrid tracking method of WCE motion, integrating magnetic sensing and image-based localization. [223] presents an approach to use the intestinal motility to localize the endoscope. These additional references complete the list for NAV in literature: [224]–[229]

- 10) *Intra and Inter-Operative Re-localization (IAO and IRO)*: The IAO based approaches focus on detecting, tracking and localizing biopsy sites during a single procedure. Primarily, these approaches focus on BSR. One of the first methods in IAO re-localization, was published by Allain *et al.* [230], [231]. In their approach, the authors proposed to compute feature points in scale-space around the biopsy location and then extracted descriptors for these points using scale invariant feature transform (SIFT) for the two endoscopic views to be matched. Then employing the epipolar constraint, a fundamental matrix was computed between the two views, that mapped the biopsy site to facilitate re-targeting. In [232] a framework for characterizing and propagation of the uncertainty in the localization of the biopsy points was presented. Mountney *et al.* [233] performed a review of various feature descriptors applied to deformable tissue tracking and in [234] proposed an Extended Kalman filter (EKF) framework for simultaneous localization and mapping (SLAM) based method for feature tracking in deformable scene, such as in laparoscopic surgery. This EKF framework was then extended in [235] for maintaining a global map of biopsy sites for endoluminal procedures, intra-operatively. The authors presented an evaluation of the EKF-SLAM on phantom models of stomach and oesophagus. Giannarou *et al.* [236] presented an affine-invariant anisotropic region detector robust to soft tissue deformations. This was used by [237] along with SIFT descriptors. The feature matching problem was then modelled as a global optimization of an Markov Random Field (MRF) labelling. Recently, Ye *et al.* [238], [239] accomplished the biopsy site re-targeting in three stages. First using the Tracking-Learning-Detection (TLD) method proposed by Kalal *et al.* [240]. TLD was used for tracking multiple regions around the selected biopsy site. Under the assumption that the regional tissue deformations can be approximated using local affine transformations, a local homography between matched region centres was estimated. In this way multiple regions around the biopsy sites are tracked, which were then used for homography estimation and mapping the biopsy sites. Wang *et al.* [241] proposed to learn a graph (atlas) from a sequence of images from several gastroscopic interventions. Considering that the stomach's deformation as not being large between similar frames the nodes of the learnt graph atlas were connected by an estimated rigid transformation. Thus, the mapping

of the biopsy sites from a single (reference) frame to subsequent frames for any given intervention was reduced to a graph search problem. Firstly, for the reference frame and the moving frame their corresponding matching nodes in the graph were computed. Using Dijkstra's algorithm, the shortest path between these matched nodes was obtained. Hence, the transformation between the reference frame and moving frame was obtained as the associated combination of rigid transforms along the shortest path between the corresponding matched nodes of the graph.

In contrast, the IRO methods attempt to provide localization between interventions. [242] proposed the use of electromagnetic tracking system (EMTS) for localizing the biopsy sites in the stomach. They construct a 3D model of the stomach using SLAM and map the biopsy points tracked using the EMTS on to the 3D model. The inter-operative registration was performed by selecting five reference points manually, during each intervention. In [243], [244], Atasoy *et al.* proposed to formulate the relocalization as a image-manifold learning process. The method involved firstly, building an adjacency graph between the images of a surveillance intervention. Normalized cross-correlation was used as the similarity measure between image frames to compute the adjacency graph. Then using laplacian eigenmaps decomposition that was proposed in [245], a linear projection matrix was computed. This approximation for projection on to the manifold was used to compute the low-dimensional representation for all the images in the intervention. Then, two separate methodologies for performing inter-operative re-localization was proposed using scene association. In [244], the scene association is performed by computing the nearest neighbour directly over the low-dimensional representation from an earlier surveillance endoscopy. However, in [243] a two-run surveillance endoscopy was suggested, in which a dummy surveillance is performed before, that was used for scene association with the actual surveillance. The authors claimed that the modified approach in [243] allowed for scene association in presence of significant structural changes in the tissue. For colonoscopic procedures, the need to provide navigational assistance is substantial. One of the earliest approaches involved combination of 3D reconstruction from pre-operative CT with endoscopic video known as virtual colonoscopy. The chief aspect of it involved computation of optical flow to estimate the ego-motion of the colonoscope. Ego-motion or visual odometry involves firstly, extracting features from the image and computing optical flow fields. Then, using the flow fields, the camera motion would be estimated. In [246] the authors presented a comparison of two ego-motion estimation schemes, supervised and unsupervised. Supervised methods, as shown in [192] require training data to be available in the form of optical-flow measurements and corresponding camera motion data. Unsupervised approaches, however, used image correspondences between video frames and multiple-view geometry to estimate endoscope motion, as

was shown in [247]. Theoretically, these methods can be applied to oesophageal procedures as well. The first endoscopy can be used to obtain a 3D reconstruction of the oesophagus and can be used in the follow-up surveillance procedures. But, the video based 3D reconstruction in GI procedures is still an open are for research. However, an additional pre-operative imaging such as CT can be used for the reconstruction of the oesophagus. Due to which, such methods were not cost-effective and aren't used as part of routine procedures.

- 11) *Lumen Detection (LD)*: By itself LD can be employed for NAV, LOC, MD etc. [248] proposes, global thresholding, followed by a differential region growing using dynamic hill clustering optimization to extract the lumen. In [249], Haar like feature combined with adaboost were used to select the most discriminative features. Then, a boosted cascade of classifiers was employed for lumen detection. Otsu thresholding was employed for segmenting darker regions of the image in [250]. A pyramidal structure of binarized images was constructed and from the smallest image, the region seed is grown back to the original image resolution to detect the lumen. In [251], the proposed method is based on the appearance and geometry of the lumen, which we defined as the darkest image region whose centre is a hub of image gradients. In [252], the proposed technique applied the Otsu's procedure recursively to obtain a coarse ROI, which is then subjected to an Iris filter operation so that a smaller enhanced region can be identified. The enhanced region was then subjected to the Otsu's procedure recursively and the process of performing Iris filter operation repeated. [253], developed a deformable region model approach to extract lumen from the endoscopic image by giving an approximate boundary plan of the lumen using minimum cross-entropy algorithm, that was then deformed to the compute the real boundary automatically.
- 12) *Uninformative Frame or Region Detection (UI)*: Section sec:challenges had earlier presented a description of the what constitutes an UI frame. It is important to note in this context that any endoscopic frame need not be completely informative or entirely UI. Thus, some methods proposed in literature also try to identify the UI regions. [254] propose UI region detection using a multi-stage approach with Chan-Vese segmentation, color range ratio, adaptive gamma correction (AGCM), and finally using canny colour edge detection operator with morphological processing. [255], propose using texture analysis of image DFT and use k -means clustering to classify UI frames. [256] propose to use L2 norm of DWT decomposition as features given to a Bayesian classifier. In [257], the local colour moments in Ohta space, along with HSV colour histogram were used as features to train an SVM classifier in the first stage of UI frame removal. In the second phase, the Gauss laguerre transform based multi-resolution decomposition was performed and the responses were thresholded. The authors also present a comparison with Gabor and wavelet based descriptors. In the methods proposed by [258], two values are computed

over a grid on the image; a) Dark Region Identification (DRI) using convolution with gaussian kernel. b) Directed Gradient Accumulation (DGA) . A UI region is then defined by low(DRI) and high(DGA). [259] proposed to perform, watershed segmentation followed by morphological closing and Frontier based region merging. After the first merging, region-based merging is performed using mean grey value to threshold over a sliding window. Five empirically chosen region profiles were used for thresholding. In [260], proposed approach involves, lumen detection based on mean shift and evaluation of coherent motility for selecting informative frames. [261], use texture feature extracted from bank of Gabor filters with a feed-forward neural network for UI classification. [262] propose three methods for UI region detection in WCE frames, using feature extracted from morphological operations, statistical features and Gabor filter based features in HSV colour space. Fuzzy k -means, Fisher test and neural network based discriminators were used. The following references give additional methods from this category proposed in literature: [263]–[270]

- 13) *Specular Highlight Detection and Removal (SHD)*: Although, specular highlights in the image constitute UI regions, this particular category of methods attempt to not only identify such regions, but also correct them. In [271], specular highlights is addressed using a segmentation method based on non-linear filtering and colour image thresholding followed by a fast inpainting method. The proposed method in [272], aims to decouple the specular and diffuse components of endoscopic imagery in order to suppress specular reflectance. A stochastic Bayesian estimation approach is introduced to estimate the specular component of endoscopic imagery. A Monte-Carlo sampling of image regions is performed for computing posterior probability. [273], describe a specular removal framework using a Dichromatic Reflection Model (DRM) and multi-resolution inpainting technique to obtain the corrected region.
- 14) *Endoscopic Reconstruction (REC)*: 3D Reconstruction in flexible endoscopic procedures is quite a challenging task. Apart from the already discussed, UI frames, presence of repeatable features in a deformable environment poses significant difficulties, if overcome, can aide in assisted diagnosis, pre-operative planning and post-operative review. The feature detectors that were discussed in ?? are used frequently used to recover the 3D from images. In [274], the tracked feature points are used for estimating camera parameters and providing an estimate of the polyp size. [275] proposed to use SIFT features using normalized SSD based monoSLAM for 3D reconstruction of the oesophagus. [276] employed Shi-Tomasi features and used them in shape from shading framework for reconstruction. [277], [278] proposed to use, affine invariant version of SIFT detector and descriptor to estimate the epipolar geometry and recover the 3D. In [279], [280], edges of colon fold contours were first detected and processed to generate the wire frame of the reconstructed virtual colon. A colon fold contour estimation algorithm

using a single colonoscopy image was proposed and the depth and shape estimation of colon folds using brightness intensity of pixels was introduced. In [281], shape-from-shading was used to reconstruct polyps for better recognition. [208] describes an approach to perform a gastric panorama by visual tracking. [214] proposes a structure from motion based method that takes advantage of a 6-DOF tracking device that is used to record the endoscope's position during a procedure. After feature tracking, a space constraint strategy is applied to remove the outliers and recover the missing data. In [45], a method to reconstruct the 3D texture surface of the GI tract using single WCE image using Shape from Shading technique is presented. [282] used, a circular generalized cylinder as a basis for 3D reconstruction of the GI tract. The model was decomposed as a series of 3D circles and a MRF framework was proposed to maximize the a posteriori estimation. In [216], a 3D model and panoramic view are incorporated into the navigation system with three improvements: selection of reference and tracking of features; perspective projection for constructing local and global panoramic view. 3D surface modelling is performed using structure from motion. The system was evaluated for three clinic applications: broadening the endoscopic view, performing non-invasive re-targeting, and determining the overall lesion locations. [283] proposes to use lumen detection in WCE to create a 3D map using inertial information from the WCE trackers.

- 15) *Endoscopic Image Enhancement (IE)*: This category refers to a class of approaches directed towards pre-processing steps to improve the quality of visible image and feature response. In [284], authors evaluate different reconstruction-based super-resolution algorithms in order to enhance the spatial resolution of endoscopic images acquired with an HD endoscope and to determine the its feasibility to study fine mucosal structures in HD endoscopy. To overcome the rather dark WCE images a adaptive contrast diffusion filtering is proposed in [285]. [286] proposes an ROI enhancement is for colour correction of regions to be inspected by GI specialists. [287] a colour enhancement of WCE frames is proposed to obtain robust texture based features. [288], proposes use of Homomorphic filtering and [94] describe an adaptive anisotropic diffusion pre-processing for image enhancement before feature extraction.
- 16) *Endoscopic Video Summarization (ES)*: This is primarily a category ascribed to wireless capsule endoscopy. Due to the large volume of frames to analyse methods have been developed to minimize this time using different methods. [289] proposes a new fast spatio-temporal technique that detects an operation scene a video segment corresponding to a single purpose diagnosis action or a single purpose therapeutic action. In [270], an approach is presented to segment WCE video. To accomplish this, firstly, colour and wavelet texture features are used to denote UI regions. Then boundaries between adjacent organs of WCE video are estimated in two levels. At course level, colour feature is utilized to draw a dissimilarity curve between

frames and the aim is to find the peak of the curve, which represents the approximate boundary. At the fine level, Hue-Saturation histogram colour feature in HSV colour space and uniform LBP texture feature from grayscale images are extracted. These features are used to train an SVM classifier for video segmentation. In [290], a two step approach to summarization is proposed. The first step consists of a semi-supervised clustering and Local Scale Learning (SS-LSL) algorithm. This algorithm is used to group video frames into prototypical clusters that summarise the CE video with constraints that are deduced from the training frames. The second step consists of a novel relational motion histogram descriptor that is designed to represent the local motion distribution between two contiguous frames. [291] proposes the use of textons for classifying video segments corresponding to different regions in the GI tract. [292] reviews various colour and texture descriptor for WCE image analysis. The segments of constant intestinal activity are detected with a robust statistical test that is based on Hoeffding's inequality in [293]. [294] propose using HSV histograms compressed using a combination of DCT and PCA for identifying different regions in the WCE video. [295] proposes a hierarchical key frame extraction algorithm based on a saliency map to automatically select a small number of key informative frames. [296] propose a method that is based on clustering using symmetric non-negative matrix factorization, initialized by the fuzzy c-means algorithm and supported by non-negative Lagrangian relaxation, to extract a subset of video scenes containing the most representative frames from an entire examination. [297], [298] propose using SURF feature points from consecutive frames, and RANSAC based matching to estimate a homography between consecutive frames for fast video browsing of WCE. An unsupervised k-window clustering is presented in [158] to cluster video frames. Each cluster is trained on a different neural network for summarization. [299] describes a novel colour-texture feature to describe the contents of the frame in a WCE video. Spectral clustering is applied to segment a WCE video into meaningful parts via shot boundary detection using the extracted features. The following references have not been detailed here; [300]–[315]

- 17) *Segmentation of Specific Tissues (IAS)*: [316] propose a three step approach to segmentation of WCE image frame. a) Local polynomial approximation algorithm which finds locally-adapted neighbourhood of each pixel; b) Colour texture analysis which describes each pixel by a vector of numerical attributes that reflect this pixel local neighbourhood characteristics; c) Performing k-means clustering based on the colour feature vector. For chromoendoscopy and NBI imaging, [317] describes the usage of various visual features individually and in combinations (edgmaps, creaseness, and color), in normalized cuts image segmentation framework. [318] describes an approach to segmenting bubbles in colonoscopic images.
- 18) *Clinical Decision Support (CDS)*: The methods described

in this category discuss approaches to build a generic tool for clinicians to provide decision support. The references described here do not target a specific disease category, but rather a system for detecting lesions and categorizing them to determine the disease type. This category can also be classified as a content based image retrieval platform, which essentially uses computer vision concepts for retrieving similar images from database to aide clinical diagnosis.

In the method proposed by [319], images are transformed to CIE-LAB space. Non-sampled contourlet transform is used to decompose the chromaticity and intensity components, representing colour and texture features. The decomposed sub-bands are modelled using Generalized Gaussian Density using a ML estimator. The resulting feature vector is then compressed using PCA. Using Least Square-SVM to perform pre-classification, which is followed by computing the kullback-leibler divergence between the features of the query image and the database. [320], proposes using GLCM, colour histogram, GIST and Gabor, wavelet, Maximum response (MR8), Leung-Malik (LM) filter bank, and the Schmid Filter banks responses as feature descriptors for image retrieval using a naive Bayes Nearest neighbour classifier. [321] presents a review of various colour and texture descriptors in to retrieve the types of frames in the endoscopic scene. A comparison is drawn using these feature descriptors by training using an SVM and an ANN classifier. [322], proposes computing a 10-bin normalized hue and saturation histograms and training a SVM classifier for retrieving the class of the tissue in the ROI. [323] proposes representing the localized features in HD endoscopy images in semantic space to generate a CBIR system for clinicians to review online selected regions. In [324], using texture features extracted from DT-CWT, the authors propose a generative model based strategy closely related to CBIR for online tissue classification. [325] proposes a novel approach to the design of a semantic, low-dimensional, encoding for endoscopic imagery. [326] discusses the development of a platform for image annotation and retrieval in GI endoscopy. A CBIR system is presented in [111], for identifying precancerous lesions in the oesophagus based on color-texture analysis. [327], explores local features (extracted by using sampling schemes such as Difference-of-Gaussians and grid sampling), BoW, and provides extensive experiments on a variety of technical aspects for feature description. For the CBIR system, an SVM classifier is investigated and its performance under different kernel types, sampling strategies for the local features, the number of classes to be considered etc. is studied. [328] reviews various feature descriptors and classifications methodologies for WCE images. In [43], authors propose combining information from multiple images, to design a supervised classification approach using an hidden markov model (HMM) framework. This framework, is prototyped with weak (k -NN) classifier to evaluate its performance for regions of the GI tract containing polyps. [329] proposes the use of

colour features in the form of Hue-Saturation Histograms and texture as SVD of local regions to develop a CBIR system for detecting Pylorus valve between stomach and intestine in WCE.

In the thesis, [330], from the decomposition of an image using the Hilbert Huang Transform, selected modes were compressed using PCA to generate a representative feature vector. In [331], LBP and its variants were used firstly, for uninformative frame removal and then in the detection of lesions developed due to Celiac disease, Crohn's disease, intestinal polyps and tumours. [332], proposes a software system that uses various colour and texture features, combined into a single feature vector. Then a feature selection model is presented, that uses, Deep Sparse SVM (DSSVM) which assigns a suitable weight to the feature dimensions like the other traditional feature selection models and directly excludes useless features from the feature pool. [333], presents an intelligent system for online endoscope image analysis. The method discusses extraction of texture features in chromatic and achromatic domains from histograms of each colour component to train an ANN. [334] proposes the use of Hue-Saturation histogram in combination with LBP to classify precancerous and cancerous lesions in multi-spectral imaging. A comparison between Logistical model trees, Naive Bayes, NN and SVM classifiers was made. In [335], [336], authors study an adaptive texture classification strategy to achieve robustness to varying degrees of degradation in training images. The papers also discuss various similarity measures in this context. [337] presents a comparison of various texture based feature descriptors; LBP and variants, multi-fractal spectrum, edge co-occurrence matrix and local phase quantization to train an SVM classifier. Approach to achieve blur invariance through blur-equalization has also been studied in the context of Celiac disease classification.

In [338], scale invariant features are extracted from different variants of the DT-CWT of image, in order to classify high-magnification colon endoscopy imagery with respect to the pit pattern scheme. To enhance the scale invariance, the DCT is applied to the feature vectors. The final descriptor contains either consist of the means and standard deviations of the subbands from a DTC-WT variant or of the Weibull parameter of these sub-bands. Readers are referred to review further publications by Häfner *et al* to study the various use of spatial frequency domain descriptors [339]–[341]. [342] presents a modified version of LBP descriptor over individual colour channels to train a NN classifier using Bhattacharyya distance. [343] presents a comparison of four cross-validation approaches leave-one-image-out, leave-one-parent-image-out, leave-one-lesion-out and leave-one-patient-out for colon polyp classification. [344] discusses the application areas for decision support in GI endoscopy and presents a review of various features for detection of adenomas in video endoscopy. [345], presents a CDS that uses geometrical and colour features from the endoscopic image. The thesis [346], provides an analysis on the detection of various

generic scene categories in the colonoscopy videos. [347] discusses usage of edge features and the extraction of most discriminative subsets using a greedy feed forward selection. The descriptors are used with a NN classifier to detect various scenes in GI endoscopy.

The reader is invited to the study following references for further incite; [205], [326], [348]–[368]

This completes the review of scene understanding and classification in GI endoscopy. Although the target application in this thesis has been the oesophagus, a review of the complete GI anatomy was performed since, no such comprehensive review was encountered in literature and a clear understanding of the application domains was felt necessary. Firstly, a description of the various state of the art algorithms was performed, to highlight the key approaches. Then, a classification based on endoscopic application was performed. 18 categories were identified ranging from disease-specific cases, such as CED and CRD, to generalized CDS systems. Application domain of reconstruction, navigation and localization form important parts of an intelligent support systems and hence have also been reviewed. The secondary aim of this categorization was to elucidate the strategic thinking observed in biomedical community, on transfer of technology to GI clinical domain.

REFERENCES

- [1] L. Laine, T. Kaltenbach, A. Barkun, K. R. McQuaid, V. Subramanian, and R. Soetikno, "Scenic international consensus statement on surveillance and management of dysplasia in inflammatory bowel disease," *Gastroenterology*, vol. 148, no. 3, pp. 639–651, 2015.
- [2] H. Inoue, H. Kashida, S. Kudo, M. Sasako, T. Shimoda, H. Watanabe, S. Yoshida, M. Guelrud, C. Lightdale, K. Wang *et al.*, "The paris endoscopic classification of superficial neoplastic lesions: esophagus, stomach, and colon: November 30 to december 1, 2002," *Gastrointestinal Endoscopy*, vol. 58, no. 6 Suppl, pp. S3–S43, 2003.
- [3] L. a. Alexandre, J. Casteleiro, and N. Nobre, "Polyp detection in endoscopic video using SVMs," *KPKDD 2007 Proc. 11th European conference on Principles and Practice of Knowledge Discovery in Databases*, vol. 4702, pp. 358–365, 2007.
- [4] L. a. Alexandre, N. Nobre, and J. Casteleiro, "Color and position versus texture features for endoscopic polyp detection," *BioMedical Engineering and Informatics: New Development and the Future - Proc. 1st International Conference on BioMedical Engineering and Informatics, BMEI 2008*, vol. 2, pp. 38–42, 2008.
- [5] S. Ameling, S. Wirth, D. Paulus, G. Lacey, and F. Vilarino, "Texture-based polyp detection in colonoscopy," in *Bildverarbeitung für die Medizin 2009*. Springer, 2009, pp. 346–350.
- [6] S. Ameling, S. Wirth, D. Paulus, and Others, *Methods for Polyp Detection in Colonoscopy Videos: A Review*. Inst. für Computervisualistik, 2009.
- [7] Q. Angermann, A. Histace, O. Romain, X. Dray, A. Pinna, and B. Granado, "Smart Videocapsule for Early Diagnosis of Colorectal Cancer: Toward Embedded Image Analysis," in *Computational Intelligence in Digital and Network Designs and Applications*, ser. Part 2: Digital, Network Designs and Applications, Chapter 12. Springer, May 2015, p. 25.
- [8] J. Bernal del Nozal, "Polyp Localization and Segmentation in Colonoscopy Images by Means of a Model of Appearance for Polyps," Ph.D. dissertation, Universitat Autònoma de Barcelona., 2014.
- [9] J. Bernal, J. Sánchez, and F. Vilarino, "Towards automatic polyp detection with a polyp appearance model," *Pattern Recognition*, vol. 45, no. 9, pp. 3166–3182, 2012.
- [10] J. Bernal, J. M. Núñez, F. J. Sánchez, and F. Vilarino, "Polyp Segmentation Method in Colonoscopy Videos by Means of MSA-DOVA Energy Maps Calculation," in *Clinical Image-Based Procedures. Translational Research in Medical Imaging*. Springer, 2014, pp. 41–49.
- [11] J. Bernal, F. J. Sánchez, G. Fernández-Esparrach, D. Gil, C. Rodríguez, and F. Vilarino, "WM-DOVA maps for accurate polyp highlighting in colonoscopy: Validation vs. saliency maps from physicians," *Computerized Medical Imaging and Graphics*, vol. 43, pp. 99–111, 2015.

- [12] H. C. Wang, W. M. Chen, Y. P. Lin, and W. C. Shen, "Tumor detecting in colonoscopic narrow-band imaging data," in *Proc. International Symposium on Intelligent Signal Processing and Communications Systems*. IEEE, 2012, pp. 564–568.
- [13] R. Kwitt and A. Uhl, "Multi-directional multi-resolution transforms for zoom-endoscopy image classification," in *Advances in Soft Computing*. Springer, 2007, vol. 45, pp. 35–43.
- [14] R. Kwitt and A. Uhl, "Color wavelet cross co-occurrence matrices for endoscopy image classification," in *Proc. 3rd International Symposium on Communications, Control, and Signal Processing (ISCCSP)*. IEEE, 2008, pp. 715–718.
- [15] R. Kwitt and A. Uhl, "Color eigen-subband features for endoscopy image classification," in *2008 IEEE International Conference on Acoustics, Speech and Signal Processing*. IEEE, 2008, pp. 589–592.
- [16] S. Gross, S. Palm, J. J. W. Tischendorf, A. Behrens, C. Trautwein, and T. Aach, "Automated classification of colon polyps in endoscopic image data," in *Proc. of SPIE Medical Imaging*, vol. 8315. International Society for Optics and Photonics, 2012, pp. 83 150W–83 150W–8.
- [17] M. Häfner, A. Uhl, and G. Wimmer, "A novel shape feature descriptor for the classification of polyps in HD colonoscopy," in *Medical Computer Vision. Large Data in Medical Imaging*. Springer, 2014, pp. 205–213.
- [18] J. Ayoub, B. Granado, Y. Mhanna, and O. Romain, "SVM based colon polyps classifier in a wireless active stereo endoscope," in *Proc. Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. IEEE, 2010, pp. 5585–5588.
- [19] S. H. Bae and K.-J. Yoon, "Polyp Detection via Imbalanced Learning and Discriminative Feature Learning," *Medical Imaging, IEEE Transactions on*, pp. 2379–2393, 2015.
- [20] D.-C. Cheng, W.-C. Ting, Y.-f. Chen, and X. Jiang, "Automatic Detection of Colorectal Polyps in Static Images," *Biomedical Engineering: Applications, Basis and Communications*, vol. 23, no. 05, pp. 357–367, 2011.
- [21] S. Engelhardt, S. Ameling, S. Wirth, and D. Paulus, "Features for classification of polyps in colonoscopy," in *CEUR Workshop Proc.*, vol. 574, 2010, pp. 350–354.
- [22] H. Eskandari, a. Talebpour, M. Alizadeh, and H. Soltanian-Zadeh, "Polyp detection in Wireless Capsule Endoscopy images by using region-based active contour model," in *19th Iranian Conference of Biomedical Engineering, ICBME 2012*. IEEE, Dec 2012, pp. 305–308.
- [23] C.-C. Hsu, Z.-Y. Yang, and C.-M. Hsu, "An Automatic Colonic Polyp Type Identification System by Narrow-Band Imaging and Focal Zone Features of Vascular Shapes and Patterns," in *2012 Third International Conference on Innovations in Bio-Inspired Computing and Applications*. IEEE, 2012, pp. 144–147.
- [24] Y. Hu, B. Song, P. J. Pickhardt, and Z. Liang, "Distance weighted 'inside disc' classifier for computer-aided diagnosis of colonic polyps," in *SPIE Medical Imaging*, L. M. Hadjiiski and G. D. Tourassis, Eds. International Society for Optics and Photonics, Mar 2015, p. 94140R.
- [25] D. K. Iakovidis, D. E. Maroulis, S. Karkanis, and A. Brokos, "A Comparative Study of Texture Features for the Discrimination of Gastric Polyps in Endoscopic Video," in *Proc. 18th IEEE Symposium on Computer-Based Medical Systems (CBMS)*. IEEE, 2005, pp. 575–580.
- [26] Y. Iwahori, A. Hattori, Y. Adachi, M. K. Bhuyan, R. J. Woodham, and K. Kasugai, "Automatic Detection of Polyp Using Hessian Filter and HOG Features," *Procedia Computer Science*, vol. 60, pp. 730–739, 2015.
- [27] S. T. Jadhav and S. H. Dabhole, "An optimal IMF selection based on fast BEEMD with Dlac analysis for detection of Polyp and Ulcer in WCE images," in *2015 2nd International Conference on Electronics and Communication Systems (ICECS)*. IEEE, Feb 2015, pp. 264–270.
- [28] A. Karargyris and N. Bourbakis, "Detection of small bowel polyps and ulcers in wireless capsule endoscopy videos," *Biomedical Engineering, IEEE Transactions on*, vol. 58, no. 10, pp. 2777–2786, 2011.
- [29] F. Martínez, J. Ruano, M. Gómez, and E. Romero, "Estimating the size of polyps during actual endoscopy procedures using a spatio-temporal characterization," *Computerized Medical Imaging and Graphics*, vol. 43, pp. 1–7, 2015.
- [30] S. Y. Park, D. Sargent, I. Spofford, K. G. Vosburgh, and Y. A-Rahim, "A colon video analysis framework for polyp detection," *Biomedical Engineering, IEEE Transactions on*, vol. 59, no. 5, pp. 1408–1418, 2012.
- [31] J. A. Ruano Balseca, "Estimation of gastrointestinal polyp size in video endoscopy," Ph.D. dissertation, Universidad Nacional de Colombia Sede Bogotá, 2013.
- [32] T. Stehle, R. Auer, S. Gross, A. Behrens, J. Wulff, T. Aach, R. Winoograd, C. Trautwein, and J. Tischendorf, "Classification of colon polyps in NBI endoscopy using vascularization features," in *Medical Imaging 2009: Computer-Aided Diagnosis, Proc. SPIE*. International Society for Optics and Photonics, 2009, pp. 72 602S–72 602S–12.
- [33] N. Tajbakhsh, C. Chi, S. R. Gurudu, and J. Liang, "Automatic polyp detection from learned boundaries," in *Proc. 11th IEEE International Symposium on Biomedical Imaging: From Nano to Macro (ISBI)*. IEEE, 2014, pp. 97–100.
- [34] N. Tajbakhsh, S. R. Gurudu, and J. Liang, "A Classification-Enhanced Vote Accumulation Scheme for Detecting Colonic Polyps," in *Abdominal Imaging. Computation and Clinical Applications*. Springer, 2013, pp. 53–62.
- [35] N. Tajbakhsh, S. R. Gurudu, and J. Liang, "A Comprehensive Computer-Aided Polyp Detection System for Colonoscopy Videos," in *Information Processing in Medical Imaging*. Springer, 2015, pp. 327–338.
- [36] N. Tajbakhsh, S. R. Gurudu, and J. Liang, "Automatic polyp detection using global geometric constraints and local intensity variation patterns," in *Proc. International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*. Springer, 2014, vol. 8674, no. Pt 2, pp. 179–187.
- [37] T. Takeda, T. Tamaki, B. Raytchev, K. Kaneda, T. Kurita, S. Yoshida, Y. Takemura, K. Onji, R. Miyaki, and S. Tanaka, "Self-training with unlabeled regions for NBI image recognition," in *International Conference on Pattern Recognition (ICPR)*. IEEE, 2012, pp. 25–28.
- [38] L. R. P. Viana, Y. Iwahori, K. Funahashi, and K. Kasugai, "Automated Polyp Detection from Endoscope Images," in *Proc. 6th International Conference on Soft Computing and Intelligent Systems and 13th International Symposium on Advanced Intelligent Systems*, 2012, pp. 2272–2275.
- [39] Y. Wang, W. Tavanapong, J. Wong, J. Oh, and P. C. de Groen, "Part-based multidirectional edge cross-sectional profiles for polyp detection in colonoscopy," *IEEE Journal of Biomedical and Health Informatics*, vol. 18, no. 4, pp. 1379–1389, 2014.
- [40] Y. Wang, W. Tavanapong, J. Wong, J. H. Oh, and P. C. de Groen, "Polyp-Alert: Near real-time feedback during colonoscopy," *Computer methods and programs in biomedicine*, vol. 120, no. 3, pp. 164–179, 2015.
- [41] Y. Yuan, B. Li, and M. Q. Meng, "Improved Bag of Feature for Automatic Polyp Detection in Wireless Capsule Endoscopy Images," *Automation Science and Engineering, IEEE Transactions on*, vol. PP, no. 99, pp. 1–7, 2015.
- [42] Y. Yuan and M. Q.-H. Meng, "A novel feature for polyp detection in wireless capsule endoscopy images," in *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2014, pp. 5010–5015.
- [43] Q. Zhao, T. Dassopoulos, G. Mullin, G. Hager, M. Q.-H. Meng, and R. Kumar, "Towards integrating temporal information in capsule endoscopy image analysis," in *Proc. Annual International Conference of IEEE Engineering in Medicine and Biology Society (EMBS)*. IEEE, Aug 2011, pp. 6627–30.
- [44] M. Q. Meng, "Polyp Detection in Wireless Capsule Endoscopy Images Using Novel Color Texture Features," in *Intelligent Control and Automation (WCICA), 2011 9th World Congress on*. IEEE, 2011, pp. 948–952.
- [45] Q. Zhao and M. Q.-H. Meng, "3D reconstruction of GI tract texture surface using Capsule Endoscopy Images," in *Proc. of IEEE International Conference on Automation and Logistics*. IEEE, 2012, pp. 277–282.
- [46] M. Zhou, G. Bao, Y. Geng, B. Alkandari, and X. Li, "Polyp detection and radius measurement in small intestine using video capsule endoscopy," in *Biomedical Engineering and Informatics (BMEI), 2014 7th International Conference on*. IEEE, 2014, pp. 237–241.
- [47] V. Charisis, L. Hadjileontiadis, and G. Sergiadis, "Lacunarity-Based Inherent Texture Correlation Approach for Wireless Capsule Endoscopy Image Analysis," in *IFMBE Proc.*, vol. 41. Springer, 2014, pp. 297–300.
- [48] V. S. Charisis, L. J. Hadjileontiadis, C. N. Liatsos, C. C. Mavrogiannis, and G. D. Sergiadis, "Capsule endoscopy image analysis using texture information from various colour models," *Computer Methods and Programs in Biomedicine*, vol. 107, no. 1, pp. 61–74, 2012.
- [49] V. Charisis, A. Tsiligiri, L. J. Hadjileontiadis, C. N. Liatsos, C. C. Mavrogiannis, and G. D. Sergiadis, "Ulcer Detection in Wireless Capsule Endoscopy Images Using Bidimensional Nonlinear Analysis," in *Proc. Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. IEEE, 2010, pp. 236–239.

- [50] N. E. Koshy and V. P. Gopi, "A new method for ulcer detection in endoscopic images," in *Electronics and Communication Systems (ICECS), 2015 2nd International Conference on*. IEEE, 2015, pp. 1725–1729.
- [51] S. Hwang and M. E. Celebi, "Polyp Detection in Wireless Capsule Endoscopy Video Based on Image Segmentations and Geometric Feature," in *Proc. on the IEEE International Conference on Acoustics Speech and Signal Processing (ICASSP)*, vol. 7. IEEE, 2010, pp. 678–681.
- [52] Y. Yuan, J. Wang, B. Li, and M. Q.-H. Meng, "Saliency Based Ulcer Detection for Wireless Capsule Endoscopy Diagnosis," *Medical Imaging, IEEE Transactions on*, vol. 34, no. 10, pp. 2046–2057, Oct 2015.
- [53] M. T. Coimbra and J. P. C. Cunha, "MPEG-7 Visual Descriptors-Contributions for Automated Feature Extraction in Capsule Endoscopy," *Circuits and Systems for Video Technology, IEEE Transactions on*, vol. 16, no. 5, pp. 628–637, 2006.
- [54] A. Eid, V. S. Charisis, L. J. Hadjileontiadis, and G. D. Sergiadis, "A curvelet-based lacunarity approach for ulcer detection from Wireless Capsule Endoscopy images," in *Proc. IEEE 26th International Symposium on Computer-Based Medical Systems (CBMS)*. IEEE, 2013, pp. 273–278.
- [55] A. Karagyris and N. Bourbakis, "Identification of ulcers in wireless capsule endoscopy videos," in *Proc. IEEE International Symposium on Biomedical Imaging: From Nano to Macro (ISBI)*. IEEE, 2009, pp. 554–557.
- [56] B. Li and M. Q. H. Meng, "Computer-based detection of bleeding and ulcer in wireless capsule endoscopy images by chromaticity moments," *Computers in Biology and Medicine*, vol. 39, no. 2, pp. 141–147, 2009.
- [57] B. Li and M. Q. H. Meng, "Computer-aided detection of bleeding regions for capsule endoscopy images," *Biomedical Engineering, IEEE Transactions on*, vol. 56, no. 4, pp. 1032–1039, 2009.
- [58] B. Li and M. Q.-H. Meng, "Capsule Endoscopy Images Classification by Color Texture and Support Vector Machine," in *Proc. on the IEEE International Conference on Automation and Logistics (ICAL)*. IEEE, 2010, pp. 126–131.
- [59] D. Y. Liu, T. Gan, N. N. Rao, G. G. Xu, B. Zeng, and H. L. Li, "Automatic Detection of Early Gastrointestinal Cancer Lesions Based on Optimal Feature Extraction from Gastroscopic Images," *Journal of Medical Imaging and Health Informatics*, vol. 5, no. 2, pp. 296–302, 2015.
- [60] X. Liu, J. Gu, Y. Xie, J. Xiong, and W. Qin, "A new approach to detecting ulcer and bleeding in Wireless capsule endoscopy images," in *Proc. IEEE-EMBS International Conference on Biomedical and Health Informatics (BHI)*. IEEE, 2012, pp. 737–740.
- [61] J. H. Park and G. Yoon, "Determination of ulcer in the digestive tract using image analysis in wireless capsule endoscopy," *Biomedical Spectroscopy and Imaging*, vol. 4, no. 4, pp. 373–390, Oct 2015.
- [62] M. Gadermayr, H. Kogler, A. Uhl, and A. Vécsei, "Comparing Endoscopic Imaging Configurations in Computer-Aided Celiac Disease Diagnosis," in *Image Processing Theory, Tools and Applications (IPTA), Proc. 5th IEEE International Conference on*. IEEE, 2015.
- [63] A. Uhl, A. Vécsei, and G. Wimmer, "Complex wavelet transform variants in a scale invariant classification of celiac disease," in *Pattern Recognition and Image Analysis*. Springer, 2011, pp. 742–749.
- [64] A. Vecsei, T. Fuhrmann, and A. Uhl, "Towards automated diagnosis of celiac disease by computer-assisted classification of duodenal imagery," *Advances in Medical, Signal and Information Processing, 2008. MEDSIP 2008. 4th IET International Conference on*, pp. 1–4, 2008.
- [65] A. Vécsei, T. Fuhrmann, M. Liedlgruber, L. Brunauer, H. Payer, and A. Uhl, "Automated classification of duodenal imagery in celiac disease using evolved Fourier feature vectors," *Computer methods and programs in biomedicine*, vol. 95, no. 2 Suppl, pp. S68–78, 2009.
- [66] M. Gadermayr, M. Liedlgruber, A. Uhl, and A. Vécsei, "Evaluation of different distortion correction methods and interpolation techniques for an automated classification of celiac disease," *Computer methods and programs in biomedicine*, vol. 112, no. 3, pp. 694–712, 2013.
- [67] M. Gadermayr, M. Liedlgruber, A. Uhl, and A. Vécsei, "Problems in distortion corrected texture classification and the impact of scale and interpolation," in *Image Analysis and Processing-ICIAP 2013*. Springer, 2013, pp. 513–522.
- [68] M. Gadermayr, V. Andreas, A. Uhl, and M. Liedlgruber, "Shape Curvature Histogram : A Shape Feature for Celiac Disease Diagnosis," in *Medical Computer Vision. Large Data in Medical Imaging*, ser. LNCS. Springer, 2012, pp. 175–184.
- [69] M. Gadermayr, A. Uhl, and A. Vécsei, "Boosting Small-Data Performance of LBP: A Case Study in Celiac Disease Diagnosis," in *Proc. 19th Scandinavian Conference on Image Analysis (SCIA)*, ser. LNCS. Springer, 2015.
- [70] M. Gadermayr, A. Uhl, and A. Vécsei, "Dealing with intra-class and intra-image variations in automatic celiac disease diagnosis," in *Bildverarbeitung für die Medizin 2015*. Springer, 2015, vol. 7623, pp. 461–466.
- [71] M. Gadermayr, A. Uhl, and A. Vécsei, "Getting one step closer to fully automatized celiac disease diagnosis," in *Proc. on the 4th International Conference on Image Processing Theory, Tools and Applications (IPTA)*. IEEE, 2014, pp. 1–5.
- [72] J. Hämmerle-Uhl, Y. Höller, A. Uhl, and A. Vécsei, "Endoscope Distortion Correction Does Not (Easily) Improve Mucosa-Based Classification of Celiac Disease," in *Proc. International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*. Springer, 2012, vol. 7512, pp. 574–581.
- [73] S. Hegenbart, R. Kwitt, M. Liedlgruber, A. Uhl, and Others, "Impact of duodenal image capturing techniques and duodenal regions on the performance of automated diagnosis of celiac disease," in *Proc. 6th International Symposium on Image and Signal Processing and Analysis (ISPA)*. IEEE, 2009, pp. 718–723.
- [74] S. Hegenbart, A. Uhl, and A. Vécsei, "Impact of histogram subset selection on classification using multi-scale lbp-operators," in *Bildverarbeitung für die Medizin 2011*. Springer, 2011, pp. 359–363.
- [75] S. Hegenbart, A. Uhl, and A. Vécsei, "Impact of endoscopic image degradations on lbp based features using one-class svm for classification of celiac disease," in *Proc. 7th International Symposium on Image and Signal Processing and Analysis (ISPA)*. IEEE, 2011, pp. 715–720.
- [76] S. Hegenbart, A. Uhl, and A. Vecsei, "On the implicit handling of varying distances and gastrointestinal regions in endoscopic video sequences with indication for celiac disease," in *Proc. 25th IEEE International Symposium on Computer-Based Medical Systems (CBMS)*. IEEE, 2012, pp. 1–6.
- [77] S. Hegenbart, A. Uhl, A. Vécsei, and G. Wimmer, "Scale invariant texture descriptors for classifying celiac disease," *Medical Image Analysis*, vol. 17, no. 4, pp. 458–474, 2013.
- [78] A. Uhl and G. Wimmer, "A systematic evaluation of the scale invariance of texture recognition methods," *Pattern Analysis and Applications*, pp. 1–25, 2014.
- [79] A. Vécsei, G. Amann, S. Hegenbart, M. Liedlgruber, and A. Uhl, "Automated Marsh-like classification of celiac disease in children using local texture operators," *Computers in Biology and Medicine*, vol. 41, no. 6, pp. 313–325, 2011.
- [80] S. Seshamani, R. Kumar, G. Mullin, T. Dassopoulos, and G. D. Hager, "A meta method for image matching," *IEEE transactions on medical imaging*, vol. 30, no. 8, pp. 1468–79, 2011.
- [81] S. Bejakovic, R. Kumar, T. Dassopoulos, G. Mullin, and G. Hager, "Analysis of Crohn's disease lesions in capsule endoscopy images," in *Proc. of IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, 2009, pp. 2793–2798.
- [82] M. Abouelenien, X. Yuan, B. Giritharan, J. Liu, and S. Tang, "Cluster-based sampling and ensemble for bleeding detection in capsule endoscopy videos," *American Journal of Science and Engineering*, vol. 2, no. 1, pp. 24–32, 2013.
- [83] G. Pan, G. Yan, X. Song, and X. Qiu, "BP neural network classification for bleeding detection in wireless capsule endoscopy," *Journal of medical engineering & technology*, vol. 33, no. 7, pp. 575–581, 2009.
- [84] G. B. Pan, G. Z. Yan, X. S. Song, and X. L. Qiu, "Bleeding detection from wireless capsule endoscopy images using improved euler distance in CIELab," *Journal of Shanghai Jiaotong University (Science)*, vol. 15, no. 2, pp. 218–223, 2010.
- [85] S. Zhou, X. Song, M. A. Siddique, J. Xu, and P. Zhou, "Bleeding Detection in Wireless Capsule Endoscopy Images Based on Binary Feature Vector," in *Proc. 5th International Conference on Intelligent Control and Information Processing (ICICIP)*, 2014, pp. 29–33.
- [86] Y. Fu, W. Zhang, M. Mandal, and M. Q. H. Meng, "Computer-aided bleeding detection in WCE video," *IEEE Journal of Biomedical and Health Informatics*, vol. 18, no. 2, pp. 636–642, 2014.
- [87] T. Ghosh, S. K. Bashar, S. A. Fattah, C. Shahnaz, and K. A. Wahid, "An Automatic Bleeding Detection Scheme in Wireless Capsule Endoscopy Based on Statistical Features in Hue Space," in *Proc. 17th International Conference on Computer and Information Technology*. IEEE, Dec 2014, pp. 22–23.
- [88] T. Ghosh, S. A. Fattah, S. K. Bashar, C. Shahnaz, K. A. Wahid, W.-P. Zhu, and M. O. Ahmad, "An automatic bleeding detection technique in wireless capsule endoscopy from region of interest," in *Digital Signal Processing (DSP), 2015 IEEE International Conference on*. IEEE, 2015, pp. 1293–1297.

- [89] K. Abe, H. Takagi, M. Minami, and H. Tian, "Computer-aided Diagnosis for Internal Hemorrhoids by Measuring the Congestive Extent in Endoscopic Images," *Journal of Biomedical Engineering and Medical Imaging*, vol. 1, no. 6, pp. 10–21, Dec 2015.
- [90] H. Chen, J. Chen, Q. Peng, G. Sun, and T. Gan, "Automatic hookworm image detection for wireless capsule endoscopy using hybrid color gradient and contourlet transform," in *Biomedical Engineering and Informatics (BMEI), 2013 6th International Conference on*. IEEE, 2013, pp. 116–120.
- [91] S. Alotaibi, S. Qasim, O. Bchir, and M. M. B. Ismail, "Empirical comparison of visual descriptors for multiple bleeding spots recognition in wireless capsule endoscopy video," in *Computer Analysis of Images and Patterns*. Springer, 2013, pp. 402–407.
- [92] N. Bourbakis, S. Makrogiannis, and D. Kaviraki, "A neural network-based detection of bleeding in sequences of WCE images," in *Proc. 5th IEEE Symposium on Bioinformatics and Bioengineering (BIBE)*. IEEE, 2005, pp. 324–327.
- [93] A. Brzeski, "Visual Features for Endoscopic Bleeding Detection," *British Journal of Applied Science & Technology*, vol. 4, no. 27, pp. 3902–3914, 2014.
- [94] I. N. Figueiredo, S. Kumar, C. Leal, and P. N. Figueiredo, "Computer-assisted bleeding detection in wireless capsule endoscopy images," *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, vol. 1, no. 4, pp. 198–210, 2013.
- [95] Y. Fu, M. Mandal, and G. Guo, "Bleeding region detection in WCE images based on color features and neural network," in *Proc. Midwest Symposium on Circuits and Systems*. IEEE, 2011, pp. 1–4.
- [96] A. R. Hassan and M. A. Haque, "Computer-aided gastrointestinal hemorrhage detection in wireless capsule endoscopy videos," *Computer methods and programs in biomedicine*, 2015.
- [97] Y. S. Jung, Y. H. Kim, D. H. Lee, and J. H. Kim, "Active blood detection in a high resolution capsule endoscopy using color spectrum transformation," in *Proc. 1st International Conference on BioMedical Engineering and Informatics (BMEI)*, vol. 1. IEEE, 2008, pp. 859–862.
- [98] a. Karagyris and N. Bourbakis, "A methodology for detecting blood-based abnormalities in wireless capsule endoscopy videos," in *Proc. 8th IEEE International Conference on Bioinformatics and BioEngineering (BIBE)*. IEEE, 2008, pp. 1–6.
- [99] P. Y. Lau and P. L. Correia, "Detection of bleeding patterns in WCE video using multiple features," in *Proc. 29th Annual International Conference of IEEE Engineering in Medicine and Biology Society (EMBS)*. IEEE, 2007, pp. 5601–5604.
- [100] Y.-G. Lee, J. H. Park, and G. Yoon, "Image analysis for locating bleeding regions in gastrointestinal endoscopy," *Biomedical Spectroscopy and Imaging*, vol. 1, no. 3, 2012.
- [101] J. Liu and X. Yuan, "Obscure bleeding detection in endoscopy images using support vector machines," *Optimization and Engineering*, vol. 10, no. 2, pp. 289–299, 2009.
- [102] M. Mathew and V. P. Gopi, "Transform based bleeding detection technique for endoscopic images," in *Electronics and Communication Systems (ICECS), 2015 2nd International Conference on*. IEEE, 2015, pp. 1730–1734.
- [103] C. K. Poh, T. M. Htwe, L. Li, W. Shen, J. Liu, J. H. Lim, K. L. Chan, and P. C. Tan, "Multi-level local feature classification for bleeding detection in Wireless Capsule Endoscopy images," in *Proc. IEEE Conference on Cybernetics and Intelligent Systems*. IEEE, 2010, pp. 76–81.
- [104] M. Ramaraj, S. Raghavan, V. Raghunath, and W. A. Khan, "Histogram Variance Controlled Bleeding Detectors for Wireless Capsule Endoscopic Images," *Journal of Medical Imaging and Health Informatics*, vol. 4, no. 4, pp. 500–510, 2014.
- [105] S. Sainju, F. M. Bui, and K. A. Wahid, "Automated bleeding detection in capsule endoscopy videos using statistical features and region growing," *Journal of Medical Systems*, vol. 38, no. 4, pp. 1–11, 2014.
- [106] S. K. Shah, P. P. Rajauria, J. Lee, and M. E. Celebi, "Classification of bleeding images in wireless capsule endoscopy using HSI color domain and region segmentation," in *URI-NE ASEE 2007 Conference*, 2007.
- [107] Y. Yuan and M. Q. H. Meng, "Automatic Bleeding Frame Detection in the Wireless Capsule Endoscopy Images," *IEEE Journal of Biomedical and Health Informatics*, pp. 1310–1315, 2015.
- [108] V. Conteduca, D. Sansonno, G. Ingravallo, S. Marangi, S. Russi, G. Lauletta, and F. Dammacco, "Barrett's esophagus and esophageal cancer: an overview," *International journal of oncology*, vol. 41, no. 2, pp. 414–424, 2012.
- [109] J. A. Evans, D. S. Early, N. Fukami, T. Ben-Menachem, V. Chandrasekhara, K. V. Chathadi, G. A. Decker, R. D. Fanelli, D. A. Fisher, K. Q. Foley *et al.*, "The role of endoscopy in barrett's esophagus and other premalignant conditions of the esophagus," *Gastrointestinal Endoscopy*, vol. 76, no. 6, pp. 1087–1094, 2012.
- [110] C.-R. Huang, Y.-T. Chen, W.-Y. Chen, H.-C. Cheng, and B.-S. Sheu, "Gastroesophageal Reflux Disease Diagnosis Using Hierarchical Heterogeneous Descriptor Fusion Support Vector Machine," *Biomedical Engineering, IEEE Transactions on*, vol. PP, no. 99, p. 1, 2015.
- [111] C. Münzenmayer, a. Kage, T. Wittenberg, and S. Mühlendorfer, "Computer-assisted diagnosis for precancerous lesions in the esophagus," *Methods of Information in Medicine*, vol. 48, no. 4, pp. 324–330, 2009.
- [112] P. Rajan, M. Canto, E. Gorospe, A. Almario, A. Kage, C. Winter, G. Hager, T. Wittenberg, and C. Münzenmayer, "Automated Diagnosis of Barrett's Esophagus With Endoscopic Images," in *World Congress on Medical Physics and Biomedical Engineering*. Springer, 2009, pp. 2189–2192.
- [113] F. van der Sommen, S. Zinger, E. Schoon, and P. de With, "Supportive automatic annotation of early esophageal cancer using local gabor and color features," *Neurocomputing*, vol. 144, pp. 92–106, 2014.
- [114] W. Whitehead, "Gastrointestinal motility disorders of the small intestine large intestine, rectum, and pelvic floor," *International Foundation for Functional Gastrointestinal Disorders*, pp. 1–20, 2001.
- [115] L. Igual, S. Seguí, and J. Vitrià, "Eigenmotion-based detection of intestinal contractions," in *Computer Analysis of Images and Patterns*. Springer, 2007, pp. 293–300.
- [116] S. Seguí, M. Drozdal, E. Zaytseva, C. Malagelada, F. Azpiroz, P. Radeva, and J. Vitrià, "Detection of Wrinkle Frames in Endoluminal Videos Using Betweenness Centrality Measures for Images," *IEEE Journal of Biomedical and Health Informatics*, vol. 18, no. 6, pp. 1831–1838, Nov 2014.
- [117] P. Spyridonos, F. Vilarinho, J. Vitrià, and P. Radeva, "Identification of intestinal motility events of capsule endoscopy video analysis," *Advanced Concepts for Intelligent Vision Systems*, pp. 531–537, 2005.
- [118] P. Spyridonos, F. Vilarinho, J. Vitrià, F. Azpiroz, and P. Radeva, "Anisotropic feature extraction from endoluminal images for detection of intestinal contractions," in *Proc. International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*, ser. Pt 2. Springer, 2006, vol. 9, pp. 161–168.
- [119] F. Vilarinho, P. Spyridonos, J. Vitrià, C. Malagelada, and P. Radeva, "A machine learning framework using SOMs: Applications in the intestinal motility assessment," in *Progress in Pattern Recognition, Image Analysis and Applications*. Springer, 2006, pp. 188–197.
- [120] F. Vilarinho, P. Spyridonos, J. Vitrià, C. Malagelada, and P. Radeva, "Linear Radial Patterns Characterization for Automatic Detection of Tonic Intestinal Contractions," in *Progress in Pattern Recognition, Image Analysis and Applications*. Springer, 2006, pp. 178–187.
- [121] F. Vilarinho, P. Spyridonos, F. Deiorio, J. Vitrià, F. Azpiroz, and P. Radeva, "Intestinal motility assessment with video capsule endoscopy: Automatic annotation of phasic intestinal contractions," *Medical Imaging, IEEE Transactions on*, vol. 29, no. 2, pp. 246–259, Feb 2010.
- [122] M. Drozdal, "Sequential image analysis for computer-aided wireless endoscopy," Ph.D. dissertation, Universitat de Barcelona, 2014.
- [123] M. Drozdal, S. Seguí, J. Vitrià, C. Malagelada, F. Azpiroz, and P. Radeva, "Adaptable image cuts for motility inspection using WCE," *Computerized medical imaging and graphics : the official journal of the Computerized Medical Imaging Society*, vol. 37, no. 1, pp. 72–80, 2013.
- [124] M. Drozdal, S. Seguí, P. Radeva, C. Malagelada, F. Azpiroz, and J. Vitrià, "Motility bar: A new tool for motility analysis of endoluminal videos," *Computers in Biology and Medicine*, 2015.
- [125] M. Drozdal, L. Igual, J. Vitrià, C. Malagelada, F. Azpiroz, and P. Radeva, "Aligning endoluminal scene sequences in wireless capsule endoscopy," in *Proc. IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops*. IEEE, 2010, pp. 117–124.
- [126] S. Ameling, S. Wirth, N. Shevchenko, T. Wittenberg, D. Paulus, and C. Münzenmayer, "Detection of lesions in colonoscopic images: a review," in *World Congress on Medical Physics and Biomedical Engineering, September 7-12, 2009, Munich, Germany*. Springer, 2010, pp. 995–998.
- [127] D. J. C. Barbosa, J. Ramos, and C. S. Lima, "Detection of small bowel tumors in capsule endoscopy frames using texture analysis based on the discrete wavelet transform," in *Proc. 30th Annual International Conference of IEEE Engineering in Medicine and Biology Society (EMBS)*. IEEE, 2008, pp. 3012–3015.
- [128] D. C. Barbosa, D. B. Roupas, J. C. Ramos, A. Tavares, and C. Lima, "Automatic small bowel tumor diagnosis by using multi-scale wavelet-

- based analysis in wireless capsule endoscopy images,” *Biomedical Engineering Online*, vol. 11, no. 3, 2012.
- [129] D. J. C. Barbosa, J. Ramos, J. H. Correia, and C. S. Lima, “Automatic detection of small bowel tumors in capsule endoscopy based on color curvelet covariance statistical texture descriptors,” in *Proc. Annual International Conference of IEEE Engineering in Medicine and Biology Society (EMBS)*. IEEE, 2009, pp. 6683–6686.
- [130] D. Barbosa, J. Ramos, and C. S. Lima, “A multi-scale comparison of texture descriptors extracted from the Wavelet and Curvelet domains for small bowel tumor detection in Capsule Endoscopy exams,” in *World Congress on Medical Physics and Biomedical Engineering, September 7-12, 2009, Munich, Germany*. Springer, 2010, pp. 1546–1549.
- [131] S. I. M. Francisco, “Recognition of Cancer using Random Forests as a Bag-of-Words Approach for Gastroenterology,” Master’s thesis, Universidade do Porto, 2015.
- [132] V. S. Kodogiannis and M. G. Boulougoura, “Neural Network-Based Approach for the Classification of Wireless-Capsule Endoscopic Images,” in *Proc. IEEE International Joint Conference on Neural Networks*, vol. 36. IEEE, 2005, pp. 2423–2428.
- [133] V. S. Kodogiannis and M. G. Boulougoura, “An Adaptive Neurofuzzy Approach for the Diagnosis in Wireless Capsule Endoscopy Imaging,” *International Journal of Information Technology*, vol. 13, no. 1, pp. 46–56, 2007.
- [134] S. Manivannan and E. Trucco, “Learning discriminative local features from image-level labelled data for colonoscopy image classification,” in *Proc. 12th IEEE International Symposium on Biomedical Imaging: From Nano to Macro (ISBI)*. IEEE, Apr 2015, pp. 420–423.
- [135] S. Manivannan, R. Wang, and E. Trucco, “Extended Gaussian-Filtered Local Binary Patterns for Colonoscopy Image Classification,” in *Proc. IEEE International Conference on Computer Vision (ICCV) Workshops*. IEEE, Dec 2013, pp. 184–189.
- [136] S. Manivannan, R. Wang, and E. Trucco, “Inter-Cluster Features for Medical Image Classification,” in *Proc. International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*. Springer, 2014, vol. 8675, pp. 345–352.
- [137] S. Manivannan, R. Wang, E. Trucco, and A. Hood, “Automatic normal-abnormal video frame classification for colonoscopy,” in *Proc. IEEE International Symposium on Biomedical Imaging: From Nano to Macro (ISBI)*. IEEE, 2013, pp. 644–647.
- [138] S. Manivannan, R. Wang, M. P. Trujillo, J. A. Hoyos, and E. Trucco, “Video-specific SVMs for colonoscopy image classification,” in *Proc. Computer-Assisted and Robotic Endoscopy Workshop, MICCAI*, vol. 8899. Springer, 2014, p. 11.
- [139] J. Bernal, F. Vilarino, and J. Sánchez, “Towards Intelligent Systems for Colonoscopy,” in *INTECH Open Access Publisher*. InTech, 2011, vol. 1, pp. 257–282.
- [140] D. Chen, M.-H. Meng, H. Wang, C. Hu, and Z. Liu, “A novel strategy to label abnormalities for wireless capsule endoscopy frames sequence,” in *2011 IEEE International Conference on Information and Automation, ICIA 2011*. IEEE, 2011, pp. 379–383.
- [141] M. Coimbra, F. Riaz, M. Areia, F. Baldaque Silva, and M. Dinis-Ribeiro, “Segmentation for classification of gastroenterology images,” in *Proc. Annual International Conference of IEEE Engineering in Medicine and Biology Society (EMBS)*. IEEE, 2010, pp. 4744–7.
- [142] B. Dhandra, R. Hegadi, M. Hangarge, and V. Malemath, “Endoscopic image classification based on active contours without edges,” *Proc. 1st International Conference on Digital Information Management*, 2007.
- [143] M. Dmitry, Z. Igor, K. Vladimir, S. Andrey, K. Timur, T. Anastasia, and K. Alexander, “Review of features and metafeatures allowing recognition of abnormalities in the images of GIT,” in *Proc. 17th IEEE Mediterranean Electrotechnical Conference (MELECON)*. IEEE, 2014, pp. 231–235.
- [144] T. Hirakawa, T. Tamaki, B. Raytchev, K. Kaneda, T. Koide, Y. Kom-inami, R. Miyaki, T. Matsuo, S. Yoshida, and S. Tanaka, “Smoothing posterior probabilities with a particle filter of dirichlet distribution for stabilizing colorectal NBI endoscopy recognition,” in *Proc. of IEEE International Conference on Image Processing (ICIP)*. IEEE, 2013, pp. 621–625.
- [145] T. Hirakawa, T. Tamaki, B. Raytchev, K. Kaneda, T. Koide, Y. Kom-inami, S. Yoshida, and S. Tanaka, “SVM-MRF segmentation of colorectal NBI endoscopic images,” in *Proc. 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBS)*. IEEE, 2014, pp. 4739–4742.
- [146] T. Hiroyasu, K. Hayashinuma, H. Ichikawa, N. Yagi, and U. Yamamoto, “Endoscope image analysis method for evaluating the extent of early gastric cancer,” in *Proc. IEEE Symposium on Computational Intelligence for Multimedia, Signal and Vision Processing (CIMSIVP)*. IEEE, 2014, pp. 1–5.
- [147] E. Hu, H. Nosato, H. Sakanashi, and M. Murakawa, “A modified anomaly detection method for capsule endoscopy images using non-linear color conversion and Higher-order Local Auto-Correlation (HLAC),” in *Proc. Annual International Conference of IEEE Engineering in Medicine and Biology Society (EMBS)*. IEEE, 2013, pp. 5477–5480.
- [148] C. Junzhou, H. Run, Z. Li, P. Qiang, and G. Tao, “Contourlet based feature extraction and classification for Wireless Capsule Endoscopic images,” in *Proc. 4th International Conference on BioMedical Engineering and Informatics (BMEI)*, vol. 1. IEEE, 2011, pp. 219–223.
- [149] S. Karkanis, D. Iakovidis, D. Maroulis, D. Karras, and M. Tzivras, “Computer-aided tumor detection in endoscopic video using color wavelet features,” *Information Technology in Biomedicine, IEEE Transactions on*, vol. 7, no. 3, pp. 141–152, 2003.
- [150] P. Y. Lau and P. L. Correia, “Analyzing Gastrointestinal Tissue Images using Multiple Features,” in *Proc. International Conference on Telecommunications*, vol. 1, 2007, pp. 435–38.
- [151] B.-P. Li and M. Q.-H. Meng, “Comparison of several texture features for tumor detection in CE images,” *Journal of Medical Systems*, vol. 36, no. 4, pp. 2463–9, 2012.
- [152] B. Li, R. Zhou, C. Yang, M. Q.-H. Meng, G. Xu, and C. Hu, “Capsule endoscopy images classification by random forests and ferns,” in *Proc. IEEE International Conference on Information Science and Technology*. IEEE, 2014, pp. 414–417.
- [153] P. Li, K. L. Chan, and S. M. Krishnan, “Learning a multi-size patch-based hybrid kernel machine ensemble for abnormal region detection in colonoscopic images,” in *Proc. IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR)*, vol. 2. IEEE, 2005, pp. 670–675.
- [154] W. Li, U. Gustafsson, and Y. A-Rahim, “Automatic colonic lesion detection and tracking in endoscopic videos,” in *Proc. of SPIE Medical Imaging*, R. M. Summers and B. van Ginneken, Eds., vol. 7963. International Society for Optics and Photonics, Mar 2011, pp. 79 632L–79 632L–8.
- [155] P. Liang, Y. Cong, and M. Guan, “A computer-aided lesion diagnose method based on gastroscope image,” in *2012 IEEE International Conference on Information and Automation*. IEEE, 2012, pp. 871–875.
- [156] C. S. Lima, J. H. Correia, J. Ramos, and D. Barbosa, “Texture classification of images from Endoscopic Capsule by using MLP and SVM- A comparative approach,” in *Proc. World Congress 2009 for Medical Physics and Biomedical Engineering*. Springer, 2009, pp. 271–274.
- [157] S. N. Lima C and M. B. De Rodríguez, “Processing algorithms for the analysis of videocolonoscopy images,” in *Proc. 38th Latin America Conference on Informatics (CLEI)*. IEEE, 2012, pp. 1–7.
- [158] G. D. Magoulas, V. P. Plagianakos, D. K. Tasoulis, and M. N. Vrahatis, “Tumor Detection in Colonoscopy Using the Unsupervised k-windows Clustering Algorithm and Neural Networks,” in *In Proc. of 4th European Symposium on Biomedical Engineering*, 2004, pp. 152–163.
- [159] G. D. Magoulas, V. P. Plagianakos, and M. N. Vrahatis, “Neural network-based colonoscopic diagnosis using on-line learning and differential evolution,” *Applied Soft Computing*, vol. 4, no. 4, pp. 369–379, 2010.
- [160] P. Majewski and W. Jedruch, “Endoscopy Images Classification with Kernel,” *Innovations in applied artificial intelligence*, pp. 400–405, 2005.
- [161] G. Mehlhorn, C. Münzenmayer, M. Benz, A. Kage, M. W. Beckmann, and T. Wittenberg, “Computer-assisted diagnosis in colposcopy: results of a preliminary experiment?” *Acta cytologica*, vol. 56, no. 5, pp. 554–559, 2012.
- [162] M. Q.-H. Meng, “Detection of lymphangiectasia disease from wireless capsule endoscopy images with adaptive threshold,” in *8th World Congress on Intelligent Control and Automation*, 2010, pp. 3088–3093.
- [163] P. W. Mewes, D. Neumann, a. L. Juloski, E. Angelopoulou, and J. Hornegger, “On-the-fly detection of images with gastritis aspects in magnetically guided capsule endoscopy,” in *Imaging*, R. M. Summers and B. van Ginneken, Eds., vol. 7963, Mar 2011, pp. 79 631I–79 631I–10.
- [164] P. W. Mewes, D. Neumann, O. Licegevic, J. Simon, A. L. Juloski, and E. Angelopoulou, “Automatic region-of-interest segmentation and pathology detection in magnetically guided capsule endoscopy,” in *Proc. International Conference on Medical Image Computing and*

- Computer-Assisted Intervention (MICCAI)*. Springer, 2011, vol. 14, no. Pt-3, pp. 141–8.
- [165] D. Mitrea, P. Mitrea, R. Badea, and M. Socaciu, “Computerized methods for the assessment and characterization of the inflammatory bowel diseases and colon cancer from ultrasound and endoscopic images,” in *Proceeding of 10th WSEAS international conference*. World Scientific and Engineering Academy and Society (WSEAS), 2011, pp. 336–343.
- [166] R. Miyaki, S. Yoshida, S. Tanaka, Y. Kominami, Y. Sanomura, T. Matsuo, S. Oka, B. Raytchev, T. Tamaki, T. Koide, K. Kaneda, M. Yoshihara, and K. Chayama, “Quantitative identification of mucosal gastric cancer under magnifying endoscopy with flexible spectral imaging color enhancement,” *Journal of Gastroenterology & Hepatology*, vol. 28, no. 5, pp. 841–847, 2013.
- [167] R. D. Nawarathna, “Detection of temporal events and abnormal images for quality analysis in endoscopy videos,” Ph.D. dissertation, University of North Texas, 2013.
- [168] M. S. Neofytou, M. S. Pattichis, C. S. Pattichis, V. Tanos, E. C. Kyriacou, and D. D. Koutouris, “Texture-based classification of hysteroscopy images of the endometrium,” in *Proc. Annual International Conference of IEEE Engineering in Medicine and Biology Society (EMBS)*. IEEE, 2006, pp. 3005–3008.
- [169] V. B. S. Prasath, I. N. Figueiredo, P. N. Figueiredo, and K. Palaniappan, “Mucosal region detection and 3D reconstruction in wireless capsule endoscopy videos using active contours,” in *Proc. Annual International Conference of IEEE Engineering in Medicine and Biology Society (EMBS)*, vol. 2012. IEEE, 2012, pp. 4014–7.
- [170] V. B. S. Prasath and R. Delhibabu, “Automatic Image Segmentation for Video Capsule Endoscopy,” in *Computational Intelligence in Medical Informatics*. Springer, 2015, pp. 73–80.
- [171] G. A. Puerto-Souza, S. Manivannan, M. Trujillo, J. Hoyos, E. Trucco, and G. Mariottini, “Enhancing normal-abnormal classification accuracy in colonoscopy videos via temporal consistency,” in *Proc. Computer-Assisted and Robotic Endoscopy Workshop, MICCAI*, 2015.
- [172] F. Riaz, M.-D. Ribeiro, P. Pimentel-Nunes, and M. Tavares Coimbra, “Integral scale histogram local binary patterns for classification of narrow-band gastroenterology images,” in *Proc. Annual International Conference of IEEE Engineering in Medicine and Biology Society (EMBS)*, July 2013, pp. 3714–3717.
- [173] F. Riaz, M. Areia, F. B. Silva, M. Dinis-Ribeiro, P. P. Nunes, and M. Coimbra, “Gabor textons for classification of gastroenterology images,” in *Proc. IEEE International Symposium on Biomedical Imaging: From Nano to Macro (ISBI)*. IEEE, Mar 2011, pp. 117–120.
- [174] F. Riaz, F. B. Silva, M. D. Ribeiro, and M. T. Coimbra, “Invariant Gabor Texture Descriptors for Classification of Gastroenterology Images,” *Biomedical Engineering, IEEE Transactions on*, vol. 59, no. 10, pp. 2893–2904, 2012.
- [175] X. Shen, K. Sun, S. Zhang, and S. Cheng, “Lesion detection of electronic gastroscope images based on multiscale texture feature,” in *IEEE International Conference on Signal Processing, Communication and Computing (ICSPCC 2012)*. IEEE, 2012, pp. 756–759.
- [176] R. Sousa, D. C. Moura, M. Dinis-ribeiro, and M. T. Coimbra, “Local Self Similar Descriptors : Comparison and Application to Gastroenterology Images,” in *36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*. IEEE, 2014, pp. 4635–4638.
- [177] K. Sun, Y. Wu, X. Lin, S. Cheng, Y. M. Zhu, and S. Zhang, “Mean shift-based lesion detection of gastroscopic images,” in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. Springer, 2012, vol. 7202 LNCS, pp. 167–174.
- [178] Kai Sun, S. Zhang, R. Yao, W. Yang, S. Cheng, and S. Zhang, “Lesion detection of gastroscopic images based on cost-sensitive boosting,” in *2011 IEEE International Workshop on Machine Learning for Signal Processing*. IEEE, Sep 2011, pp. 1–6.
- [179] Z. Sun, B. Li, R. Zhou, H. Zheng, and M. Q. H. Meng, “Removal of Non-Informative Frames for Wireless Capsule Endoscopy Video Segmentation,” in *IEEE International Conference on Automation and Logistics, ICAL*, Aug 2012, pp. 294–299.
- [180] D. Surangsrirat, M. Tapia, and W. Z. W. Zhao, “Classification of endoscopic images using support vector machines,” in *IEEE SoutheastCon 2010 (SoutheastCon), Proc. of the*. IEEE, 2010, pp. 436–439.
- [181] P. M. Szczypiński, R. D. Sriram, P. V. Sriram, and D. N. Reddy, “A model of deformable rings for interpretation of wireless capsule endoscopic videos,” *Medical Image Analysis*, vol. 13, no. 2, pp. 312–324, 2009.
- [182] P. Szczypiński and A. Klepaczko, “Automated recognition of abnormal structures in WCE images based on texture most discriminative descriptors,” in *Advances in Intelligent and Soft Computing*. Springer, 2010, vol. 84, pp. 263–270.
- [183] P. Szczypiński, A. Klepaczko, and M. Strzelecki, “An intelligent automated recognition system of abnormal structures in wce images,” in *Proc. 6th International Conference on Hybrid Artificial Intelligent Systems - Volume Part I*, ser. HAIS’11. Springer, 2011, pp. 140–147.
- [184] M. P. Tjoa and S. M. Krishnan, “Feature extraction for the analysis of colon status from the endoscopic images,” *BioMedical Engineering Online*, vol. 2, no. 1, p. 9, 2003.
- [185] A. Uhl, G. Wimmer, and M. Hafner, “Shape and size adapted local fractal dimension for the classification of polyps in HD colonoscopy,” in *Proc. of IEEE International Conference on Image Processing (ICIP)*. IEEE, Oct 2014, pp. 2299–2303.
- [186] H. Vu, T. Echigo, Y. Imura, Y. Yanagawa, and Y. Yagi, “Segmenting Reddish Lesions in Capsule Endoscopy Images Using a Gastrointestinal Color Space,” in *2014 22nd International Conference on Pattern Recognition*. IEEE, 2014, pp. 3263–3268.
- [187] H. Wang, D. Chen, M.-H. Meng, C. Hu, and Z. Liu, “Robust abnormal wireless capsule endoscopy frames detection based on least squared density ratio algorithm,” in *2011 IEEE International Conference on Information and Automation, ICIA 2011*. IEEE, 2011, pp. 324–328.
- [188] Y. Yanagawa, T. Echigo, H. Vu, H. Okazaki, Y. Fujiwara, T. Arakawa, and Y. Yagi, “Tracking abnormalities in video capsule endoscopy using surrounding features with a triangular constraint,” in *Proc. 9th IEEE International Symposium on Biomedical Imaging (ISBI)*. IEEE, 2012, pp. 578–581.
- [189] R. Yao, S. Zhang, W. Yang, S. Cheng, and Y. Chen, “Abnormality detection on gastroscopic images using patches assembled by local weights,” in *2010 International Conference of Medical Image Analysis and Clinical Application (MIACA)*. IEEE, 2010, pp. 38–41.
- [190] X. Yuan, B. Giritharan, M. Abouelenen, J. Liu, and X. Yuan, “Geometric Incremental Support Vector Machine for Object Detection from Capsule Endoscopy Videos,” in *Computer-Aided Cancer Detection and Diagnosis: Recent Advances*. Society of Photo-Optical Instrumentation Engineers, 2013.
- [191] M. A. Armin, H. De Visser, G. Chetty, C. Dumas, D. Conlan, F. Grimpen, and O. Salvado, “Visibility Map: A New Method in Evaluation Quality of Optical Colonoscopy,” in *Proc. International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*. Springer, 2015, pp. 396–404.
- [192] C. S. Bell, K. L. Obstein, and P. Valdastrì, “Image partitioning and illumination in image-based pose detection for teleoperated flexible endoscopes,” *Artificial intelligence in medicine*, vol. 59, no. 3, pp. 185–196, 2013.
- [193] D. K. Iakovidis, E. Spyrou, and D. Diamantis, “Efficient homography-based video visualization for wireless capsule endoscopy,” in *13th IEEE International Conference on Bioinformatics and BioEngineering*. IEEE, 2013, pp. 1–4.
- [194] D. K. Iakovidis, E. Spyrou, D. Diamantis, and I. Tsiompanidis, “Capsule endoscope localization based on visual features,” in *Bioinformatics and Bioengineering (BIBE), 2013 IEEE 13th International Conference on*. IEEE, 2013, pp. 1–4.
- [195] M. Sfakiotakis, X. Zabulis, and D. P. Tsakiris, “Endoscopic capsule line-of-sight alignment by visual servoing,” in *7th Intl. Conf. on Wearable Micro and Nano Technologies for Personalized Health (pHealth 2010)*, 2010.
- [196] G. Bao, L. Mi, Y. Geng, M. Zhou, and K. Pahlavan, “A video-based speed estimation technique for localizing the wireless capsule endoscope inside gastrointestinal tract,” in *Engineering in Medicine and Biology Society (EMBC), 2014 36th Annual International Conference of the IEEE*. IEEE, 2014, pp. 5615–5618.
- [197] G. Bao, Y. Ye, U. Khan, X. Zheng, and K. Pahlavan, “Modeling of the Movement of the Endoscopy Capsule inside GI Tract based on the Captured Endoscopic Images,” in *International Conference on Modeling, Simulation and Visualization Methods, Las Vegas*, 2012.
- [198] G. Bao and K. Pahlavai, “Motion estimation of the endoscopy capsule using region-based kernel svm classifier,” in *Electro/Information Technology (EIT), 2013 IEEE International Conference on*. IEEE, 2013, pp. 1–5.
- [199] G. Bao, K. Pahlavan, and L. Mi, “Hybrid Localization of Microbotic Endoscopic Capsule Inside Small Intestine by Data Fusion of Vision and RF Sensors,” *Sensors Journal, IEEE*, vol. 15, no. 5, pp. 2669–2678, 2015.
- [200] G. Bao, L. Mi, and K. Pahlavan, “A video aided RF localization technique for the wireless capsule endoscope (WCE) inside small intestine,” in *Proc. 8th International Conference on Body Area Net-*

- works. Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering, 2013, pp. 55–61.
- [201] C. S. Bell, G. A. Puerto, G.-L. Mariottini, and P. Valdastri, “Six DOF motion estimation for teleoperated flexible endoscopes using optical flow: A comparative study,” in *Proc. IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, May 2014, pp. 5386–5392.
- [202] M. R. Burkhardt, T. D. Soper, W. J. Yoon, and E. J. Seibel, “Controlling the trajectory of a flexible ultrathin endoscope for fully automated bladder surveillance,” *Mechatronics, IEEE/ASME Transactions on*, vol. 19, no. 1, pp. 366–373, 2014.
- [203] H. Chettaoui, G. Thomann, C. B. Amar, and T. Redarce, “Extracting and tracking Colon’s “Pattern” from Colonoscopic Images,” in *IEEE Canadian Conference on Computer and Robot Vision*. IEEE, 2006, pp. 65–71.
- [204] G. N. Khan and D. F. Gillies, “Vision based navigation system for an endoscope,” *Image and Vision Computing*, vol. 14, no. 10, pp. 763–772, 1996.
- [205] C. K. Kwoh, G. N. Khan, and D. F. Gillies, “Automated Endoscope Navigation and Advisory System from medical imaging,” in *Proc. of SPIE International Conference on Physiology and Function for Multi-dimensional Images*. International Society for Optics and Photonics, 1999, pp. 214–224.
- [206] D. Liu, Y. Cao, W. Tavanapong, J. Wong, J. Oh, and P. C. de Groen, “Quadrant coverage histogram: a new method for measuring quality of colonoscopic procedures,” in *Proc. Annual International Conference of IEEE Engineering in Medicine and Biology Society (EMBS)*, vol. 2007. IEEE, 2007, pp. 3470–3.
- [207] J. Liu, K. R. Subramanian, and T. S. Yoo, “A robust method to track colonoscopy videos with non-informative images,” *International Journal of Computer Assisted Radiology and Surgery*, vol. 8, no. 4, pp. 575–592, 2013.
- [208] J. Liu, B. Wang, W. Hu, J. Li, H. Duan, and J. Si, “Global and Local Panoramic Views for Gastroscopy: An Assisted Method of Gastroscopic Lesion Surveillance,” *Biomedical Engineering, IEEE Transactions on*, vol. 62, no. 9, pp. 2296–2307, 2015.
- [209] A. Mekaouar, C. Ben Amar, and T. Redarce, “New vision based navigation clue for a regular colonoscope’s tip,” in *Proc. of SPIE*, vol. 7261. International Society for Optics and Photonics, 2009, pp. 72 611B–72 611B–9.
- [210] R. Reilink, S. Stramigioli, and S. Misra, “Image-based flexible endoscope steering,” in *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2010, pp. 2339–2344.
- [211] R. Reilink, S. Stramigioli, and S. Misra, “Pose reconstruction of flexible instruments from endoscopic images using markers,” in *Proc. IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, 2012, pp. 2938–2943.
- [212] N. Van Der Stap, R. Reilink, S. Misra, I. a. M. J. Broeders, and F. Van Der Heijden, “The use of the focus of expansion for automated steering of flexible endoscopes,” in *Proc. IEEE RAS and EMBS International Conference on Biomedical Robotics and Biomechanics*. IEEE, 2012, pp. 13–18.
- [213] N. van der Stap, C. H. Slump, I. a. M. J. Broeders, and F. van der Heijden, “Image-Based Navigation for a Robotized Flexible Endoscope,” in *Proc. Computer-Assisted and Robotic Endoscopy Workshop, MICCAI*. Springer, 2014, vol. 8999, pp. 77–87.
- [214] B. Wang, J. Liu, Y. Zong, and H. Duan, “Dynamic 3D Reconstruction of Gastric Internal Surface Under Gastroscopy,” *Journal of Medical Imaging and Health Informatics*, vol. 4, no. 5, pp. 797–802, 2014.
- [215] D. Wang, X. Xie, G. Li, Z. Yin, and Z. Wang, “A Lumen Detection-Based Intestinal Direction Vector Acquisition Method for Wireless Endoscopy Systems,” *Biomedical Engineering, IEEE Transactions on*, vol. 62, no. 3, pp. 807–819, Mar 2015.
- [216] Y. Zong, W. Hu, J. Liu, X. Zhang, B. Wang, H. Duan, and J. Si, “Incorporation of 3D Model and Panoramic View for Gastroscopic Lesion Surveillance,” in *Image and Graphics*. Springer, 2015, pp. 438–445.
- [217] J. Bulat, K. Duda, M. Duplaga, R. Fraczek, A. Skalski, M. Socha, P. Turcza, and T. P. Zielinski, “Data processing tasks in wireless GI endoscopy: image-based capsule localization and navigation and video compression,” in *Proc. 29th Annual International Conference of IEEE Engineering in Medicine and Biology Society (EMBS)*, ser. 3. IEEE, 2007, pp. 2815–8.
- [218] K. Duda, T. Zielinski, R. Fraczek, J. Bulat, and M. Duplaga, “Localization of Endoscopic Capsule in the GI Tract Based on MPEG-7 Visual Descriptors,” *The Proc. IEEE International Workshop on Imaging Systems and Techniques*, vol. 1, pp. 1–4, 2007.
- [219] I. N. Figueiredo, C. Leal, L. Pinto, P. N. Figueiredo, and R. Tsai, “An Elastic Image Registration Approach for Wireless Capsule Endoscope Localization,” *arXiv preprint arXiv:1504.06206*, 2015.
- [220] L. Igual, J. Vitrià, F. Vilarinho, S. Seguí, C. Malagelada, F. Azpiroz, and P. Radeva, “Automatic discrimination of duodenum in wireless capsule video endoscopy,” in *IFMBE Proc.*, vol. 22. Springer, 2008, pp. 1536–1539.
- [221] L. Liu, C. Hu, W. Cai, and M. Q. H. Meng, “Capsule endoscope localization based on computer vision technique,” in *Proc. Annual International Conference of IEEE Engineering in Medicine and Biology Society (EMBS)*, vol. 2009. IEEE, 2009, pp. 3711–3714.
- [222] L. Liu, W. Liu, C. Hu, and M. Q. H. Meng, “Hybrid magnetic and vision localization technique of capsule endoscope for 3D recovery of pathological tissues,” in *Proc. World Congress on Intelligent Control and Automation (WCICA)*. IEEE, 2011, pp. 1019–1023.
- [223] L. Mi, G. Bao, and K. Pahlavan, “Geometric estimation of intestinal contraction for motion tracking of video capsule endoscope,” in *SPIE Medical Imaging*, vol. 9036. International Society for Optics and Photonics, 2014, p. 90360B.
- [224] J. M. Núñez, J. Bernal, M. Ferrer, and F. Vilarinho, “Impact of Keypoint Detection on Graph-Based Characterization of Blood Vessels in Colonoscopy Videos,” in *Proc. Computer-Assisted and Robotic Endoscopy Workshop, MICCAI*. Springer, 2014, pp. 22–33.
- [225] G. A. Puerto-souza, A. N. Staranowicz, C. S. Bell, and G.-I. Mariottini, “A Comparative Study of Ego-Motion Estimation Algorithms for Teleoperated Robotic Endoscopes,” in *Proc. Computer-Assisted and Robotic Endoscopy Workshop, MICCAI*, vol. 8899. Springer, 2014, pp. 64–76.
- [226] E. Spyrou, D. K. Iakovidis, S. Niafas, and A. Koulaouzidis, “Comparative Assessment of Feature Extraction Methods for Visual Odometry in Wireless Capsule Endoscopy,” *Computers in Biology and Medicine*, 2015.
- [227] T. D. Than, G. Alici, H. Zhou, and W. Li, “A review of localization systems for robotic endoscopic capsules,” *Biomedical Engineering, IEEE Transactions on*, vol. 59, no. 9, pp. 2387–2399, 2012.
- [228] Y. Wang, W. Tavanapong, J. S. Wong, J. Oh, and P. C. De Groen, “Detection of quality visualization of appendiceal orifices using local edge cross-section profile features and near pause detection,” *Biomedical Engineering, IEEE Transactions on*, vol. 57, no. 3, pp. 685–695, 2010.
- [229] M. Zhou, G. Bao, and K. Pahlavan, “Measurement of Motion Detection of Wireless Capsule Endoscope Inside Large Intestine,” in *36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*. IEEE, 2014, pp. 5591–5594.
- [230] B. Allain, M. Hu, L. B. Lovat, R. Cook, S. Ourselin, and D. Hawkes, “Biopsy site re-localisation based on the computation of epipolar lines from two previous endoscopic images,” in *Proc. International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*, vol. 12. Springer, Heidelberg, Jan 2009, pp. 491–8.
- [231] B. Allain, M. Hu, L. B. Lovat, R. J. Cook, T. Vercauteren, S. Ourselin, and D. J. Hawkes, “A system for biopsy site re-targeting with uncertainty in gastroenterology and oropharyngeal examinations,” in *Proc. International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*, vol. 13. Springer, Jan 2010, pp. 514–21.
- [232] B. Allain, “Re-localisation of microscopic lesions in their macroscopic context for surgical instrument guidance,” Ph.D. dissertation, UCL (University College London), 2012.
- [233] P. Mountney, B. Lo, S. Thienjarus, D. Stoyanov, and G. Zhong-Yang, “A probabilistic framework for tracking deformable soft tissue in minimally invasive surgery,” in *Proc. International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*. Springer, 2007, pp. 34–41.
- [234] P. Mountney, D. Stoyanov, A. Davison, and G.-Z. Yang, “Simultaneous stereoscopic localization and soft-tissue mapping for minimal invasive surgery,” in *Proc. International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*. Springer, 2006, pp. 347–354.
- [235] P. Mountney, S. Giannarou, D. Elson, and G.-Z. Yang, “Optical biopsy mapping for minimally invasive cancer screening,” in *Proc. International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*. Springer, 2009, pp. 483–490.
- [236] S. Giannarou, M. Visentini-Scarzanella, and G.-Z. Yang, “Affine-invariant anisotropic detector for soft tissue tracking in minimally invasive surgery,” in *Proc. IEEE International Symposium on Biomedical Imaging: From Nano to Macro (ISBI)*. IEEE, 2009, pp. 1059–1062.

- [237] S. Atasoy, B. Glocker, S. Giannarou, D. Mateus, A. Meining, G.-Z. Yang, and N. Navab, "Probabilistic region matching in narrow-band endoscopy for targeted optical biopsy," in *Proc. International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*. Springer, 2009, pp. 499–506.
- [238] M. Ye, S. Giannarou, N. Patel, J. Teare, and G.-Z. Yang, "Pathological site retargeting under tissue deformation using geometrical association and tracking," in *Proc. International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*. Springer, 2013, pp. 67–74.
- [239] M. Ye, E. Johns, S. Giannarou, and G.-Z. Yang, "Online scene association for endoscopic navigation," in *Proc. International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*. Springer, 2014, pp. 316–323.
- [240] Z. Kalal, K. Mikolajczyk, and J. Matas, "Tracking-learning-detection," *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, vol. 34, no. 7, pp. 1409–1422, 2012.
- [241] B. Wang, W. Hu, J. Liu, J. Si, and H. Duan, "Gastrosopic image graph: Application to noninvasive multitarget tracking under gastroscopy," *Computational and mathematical methods in medicine*, vol. 2014, 2014.
- [242] J. Liu, B. Wang, W. Hu, Y. Zong, J. Si, and H. Duan, "A non-invasive navigation system for retargeting gastrosopic lesions," *Bio-medical materials and engineering*, vol. 24, no. 6, pp. 2673–2679, 2014.
- [243] S. Atasoy, D. Mateus, A. Meining, G.-Z. Yang, and N. Navab, "Targeted optical biopsies for surveillance endoscopies," in *Proc. International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*. Springer, 2011, pp. 83–90.
- [244] S. Atasoy, D. Mateus, A. Meining, G.-Z. Yang, and N. Navab, "Endoscopic video manifolds for targeted optical biopsy," *Medical Imaging, IEEE Transactions on*, vol. 31, no. 3, pp. 637–653, 2012.
- [245] X. He, S. Yan, Y. Hu, P. Niyogi, and H.-J. Zhang, "Face recognition using laplacianfaces," *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, vol. 27, no. 3, pp. 328–340, 2005.
- [246] G. A. Puerto-Souza, A. N. Staranowicz, C. S. Bell, P. Valdastrì, and G.-L. Mariottini, "A comparative study of ego-motion estimation algorithms for teleoperated robotic endoscopes," in *Computer-Assisted and Robotic Endoscopy Workshop at MICCAI*. Springer, 2014, pp. 64–76.
- [247] J. Liu, K. Subramanian, T. Yoo, and R. V. Uitert, "A stable optic-flow based method for tracking colonoscopy images," in *Proc. IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops*. IEEE, 2008, pp. 1–8.
- [248] K. V. Asari, "A fast and accurate segmentation technique for the extraction of gastrointestinal lumen from endoscopic images," *Medical engineering & physics*, vol. 22, no. 2, pp. 89–96, 2000.
- [249] G. Gallo and A. Torrisi, "Lumen Detection in Endoscopic Images : A Boosting Classification Approach," *International Journal on Advances in Intelligent Systems*, vol. 5, no. 1 & 2, 2012.
- [250] S. Kumar, K. V. Asari, and R. Zadhakrishnan, "Real-time automatic extraction of lumen region and boundary from endoscopic images," *Medical & Biological Engineering & Computing*, vol. 37, no. 5, pp. 600–604, 1999.
- [251] C. Sánchez, J. Bernal, D. Gil, and F. J. Sánchez, "On-Line Lumen Centre Detection in Gastrointestinal and Respiratory Endoscopy," in *Clinical image-based procedures. Translational Research in Medical Imaging*. Springer, 2014, pp. 31–38.
- [252] H. Tian, T. Srikanthan, and K. V. Asarf, "A Recursive Otsu-Iris Filter Technique for High-speed Detection of Lumen Region from Endoscopic Images," in *Applied Imagery Pattern Recognition Workshop, AIPR 2001 30th*. IEEE, 2001, pp. 182–186.
- [253] M. Tjoa, S. Krishnan, and M. Zheng, "A novel endoscopic image analysis approach using deformable region model to aid in clinical diagnosis," in *Proc. 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. IEEE, 2003, vol. 1, no. 2, pp. 710–713.
- [254] M. Alizadeh, K. Sharzei, A. Talebpour, H. Soltanian-Zadeh, H. Eskandari, and O. H. Maghsoudi, "Detection of uninformative regions in wireless capsule endoscopy images," in *Biomedical Engineering Conference (NEBEC), 2015 41st Annual Northeast*. IEEE, 2015, pp. 1–2.
- [255] Y. H. An, S. Hwang, J. Oh, J. Lee, W. Tavanapong, P. C. de Groen, and J. Wong, "Informative-frame filtering in endoscopy videos," in *Medical Imaging*. International Society for Optics and Photonics, 2005, pp. 291–302.
- [256] M. Arnold, A. Ghosh, G. Lacey, S. Patchett, and H. Mulcahy, "Indistinct frame detection in colonoscopy videos," in *Machine Vision and Image Processing Conference, 2009. IMVIP'09. 13th International*. IEEE, 2009, pp. 47–52.
- [257] M. K. Bashar, T. Kitasaka, Y. Suenaga, Y. Mekada, and K. Mori, "Automatic detection of informative frames from wireless capsule endoscopy images," *Medical Image Analysis*, vol. 14, no. 3, pp. 449–470, 2010.
- [258] J. Bernal, D. Gil, C. Sánchez, and F. J. Sánchez, "Discarding Non Informative Regions for Efficient Colonoscopy Image Analysis," in *Proc. Computer-Assisted and Robotic Endoscopy Workshop, MICCAI*. Springer, 2014, pp. 1–10.
- [259] J. B. del Nozal, J. S. Pujadas, and F. V. Freire, "Reduction of pattern search area in colonoscopy images by merging non-informative regions," in *28th Congreso Anual de la Sociedad Española de Ingeniería Biomédica*, 2010.
- [260] Y. Fan, M. Q.-H. Meng, and B. Li, "A novel method for informative frame selection in wireless capsule endoscopy video," in *Proc. Annual International Conference of IEEE Engineering in Medicine and Biology Society (EMBS)*, vol. 2011, Jan 2011, pp. 4864–7.
- [261] M. Ionescu, C. C. Vere, O. A. Vătămanu, A. Tudor, and G.-I. Mihalăş, "Informative Frames Detection in Wireless Capsule Videos Using Gabor Filters," *Automatic Control and Computer Science, Transactions on*, vol. 58(72), Mar 2013.
- [262] O. Maghsoudi, A. Talebpour, H. Sotanian-Zadeh, M. Alizadeh, and H. Soleimani, "Informative and Uninformative Regions Detection in WCE Frames," *Journal of Advanced Computing*, vol. 3, no. 1, pp. 12–34, 2014.
- [263] M. Drodzdzal, S. Seguí, C. Malagelada, F. Azpiroz, J. Vitrià, and P. Radeva, "Interactive labeling of WCE images," in *Pattern Recognition and Image Analysis*. Springer, 2011, vol. 6669 LNCS, pp. 143–150.
- [264] J. Oh, S. Hwang, J. Lee, W. Tavanapong, J. Wong, and P. C. de Groen, "Informative frame classification for endoscopy video," *Medical Image Analysis*, vol. 11, no. 2, pp. 110–127, Apr 2007.
- [265] N. Rangseekajee and S. Phongsuphap, "Endoscopy Video Frame Classification Using Edge-based Information Analysis Pre-processing," in *Computing in Cardiology*, vol. 38. IEEE, 2011, pp. 549–552.
- [266] N. Rangseekajee, M. Lohvithee, and I. Nilkhamhang, "Informative frame classification method for real-time analysis of colonoscopy video," in *6th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology*, vol. 2. IEEE, May 2009, pp. 1076–1079.
- [267] N. Tajbaksh, C. Chi, H. Sharma, Q. Wu, S. R. Gurudu, and J. Liang, "Automatic Assessment of Image Informativeness in Colonoscopy," in *Abdominal Imaging. Computational and Clinical Applications*. Springer, 2014, pp. 151–158.
- [268] S. Wang, D. Tian, Y. Cong, Y. Yang, Y. Tang, and H. Zhao, "Automatic gastroscopy video quality assessment," in *Proc. IEEE International Conference on Robotics and Biomimetics (ROBIO)*. IEEE, Dec 2014, pp. 2709–2714.
- [269] S. Wang, Y. Cong, J. Cao, Y. Yang, Y. Tang, H. Zhao, and H. Yu, "Scalable gastroscopic video summarization via similar-inhibition dictionary selection," *Artificial Intelligence in Medicine*, 2015.
- [270] R. Zhou, B. Li, Z. Sun, C. Hu, and M. Q.-H. Meng, "Wireless capsule endoscopy video automatic segmentation," in *Robotics and Biomimetics (ROBIO), 2012 IEEE International Conference on*. IEEE, 2012, pp. 825–830.
- [271] M. Arnold, S. Ameling, A. Ghosh, and G. Lacey, "Quality Improvement of Endoscopy Videos," in *Proc. 8th IASTED International Conference on Biomedical Engineering, Innsbruck, Austria*. ACTA Press, 2011.
- [272] B. Chwyl, A. G. Chung, A. Wong, and D. A. Clausi, "Specular Reflectance Suppression in Endoscopic Imagery via Stochastic Bayesian Estimation," in *Image Analysis and Recognition*. Springer, 2015, pp. 385–393.
- [273] O. Meslouhi, M. Kardouchi, H. Allali, T. Gadi, and Y. A. Benkadour, "Automatic detection and inpainting of specular reflections for colposcopic images," *Central European Journal of Computer Science*, vol. 1, no. 3, pp. 341–354, 2011.
- [274] Z. Cai, C. Hu, W. Lin, and W.-a. Yang, "A Feature Point Extraction and Matching Algorithm for Wireless Capsule Endoscope Image," in *Information and Automation (ICIA), 2013 IEEE International Conference on*. IEEE, Aug 2013, pp. 606–611.
- [275] V. Castaneda, S. Atasoy, D. Mateus, N. Navab, and a. Meining, "Reconstructing the Esophagus Surface from Endoscopic Image Sequences," in *Proc. 5th Russian-Bavarian Conference on Bio-Medical Engineering*, 2009.

- [276] G. Ciuti, M. Visentini-Scarzanella, A. Dore, A. Menciassi, P. Dario, and G. Z. Yang, "Intra-operative monocular 3D reconstruction for image-guided navigation in active locomotion capsule endoscopy," in *Proc. IEEE RAS and EMBS International Conference on Biomedical Robotics and Biomechatronics*. IEEE, 2012, pp. 768–774.
- [277] Y. Fan and M. Q.-H. Meng, "3D reconstruction of the WCE images by affine SIFT method," in *2011 9th World Congress on Intelligent Control and Automation*. IEEE, June 2011, pp. 943–947.
- [278] Y. Fan, M.-H. Meng, and B. Li, "3D reconstruction of wireless capsule endoscopy images," in *Proc. Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBS)*. IEEE, 2010, pp. 5149–5152.
- [279] D. Hong, W. Tavanapong, J. Wong, J. Oh, and P. C. de Groen, "3D Reconstruction of virtual colon structures from colonoscopy images," *Computerized Medical Imaging and Graphics*, vol. 38, no. 1, pp. 22–33, 2014.
- [280] D. Hong, "3d colon segment and endoscope motion reconstruction from endoscopy video," Ph.D. dissertation, Iowa State University, 2012.
- [281] A. Koulaouzidis and A. Karargyris, "Three-dimensional image reconstruction in capsule endoscopy," *World Journal of Gastroenterology*, vol. 18, no. 31, pp. 4086–90, 2012.
- [282] J. Zhou, A. Das, F. Li, and B. Li, "Circular generalized cylinder fitting for 3D reconstruction in endoscopic imaging based on MRF," in *Proc. IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops*. IEEE, June 2008, pp. 1–8.
- [283] Y. Abu-Kheil, G. Ciuti, M. Mura, J. Dias, P. Dario, and L. Seneviratne, "Vision and inertial-based image mapping for capsule endoscopy," in *Proc. International Conference on Information and Communication Technology Research (ICTRC)*. IEEE, 2015, pp. 84–87.
- [284] M. Häfner, M. Liedlgruber, and A. Uhl, "Super-Resolution Techniques Evaluated in the Context of HD Endoscopic Imaging," Universität Salzburg, Tech. Rep., 2013.
- [285] B. Li and M. Q.-H. Meng, "Wireless capsule endoscopy images enhancement via adaptive contrast diffusion," *Journal of Visual Communication and Image Representation*, vol. 23, no. 1, pp. 222–228, 2012.
- [286] H. Vu, T. Echigo, K. Yagi, H. Okazaki, Y. Fujiwara, Y. Yagi, and T. Arakawa, "Image-enhanced capsule endoscopy preserving the original color tones," in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. Springer, 2012, vol. 7029 LNCS, pp. 35–43.
- [287] V. S. Charisis, C. Katsimerou, L. J. Hadjileontiadis, C. N. Liatsos, and G. D. Sergiadis, "Computer-aided capsule endoscopy images evaluation based on color rotation and texture features: An educational tool to physicians," in *Proc. 26th IEEE International Symposium on Computer-Based Medical Systems (CBMS)*. IEEE, 2013, pp. 203–208.
- [288] V. Georgieva, S. Nagy, A. Horvath, and E. Kamenova, "An Approach for Pit Pattern Recognition in Colonoscopy Images," *Egyptian Computer Science Journal*, vol. 39, no. 2, 2015.
- [289] C. Zhang, W. Tavanapong, J. Wong, P. C. de Groen, and J. Oh, "Cable Footprint History: Spatio-Temporal Technique for Instrument Detection in Gastrointestinal Endoscopic Procedures," in *Proc. International Conference on Image Processing, Computer Vision, and Pattern Recognition (IPCV)*. The Steering Committee of The World Congress in Computer Science, Computer Engineering and Applied Computing (WorldComp), 2015, p. 308.
- [290] M. M. B. Ismail and O. Bchir, "CE Video Summarization Using Relational Motion Histogram Descriptor," *Journal of Image and Graphics*, vol. 3, no. 1, 2015.
- [291] G. Gallo and E. Granata, "WCE video segmentation using textons," in *Proc. of SPIE Medical Imaging*. International Society for Optics and Photonics, 2010, pp. 76 230X–76 230X–7.
- [292] M. Fisher and M. Mackiewicz, "Colour Image Analysis of Wireless Capsule Endoscopy Video: A Review," in *Color Medical Image Analysis*. Springer, 2013, pp. 129–144.
- [293] M. Drozdal, J. Vitria, S. Segui, C. Malagelada, F. Azpiroz, and P. Radeva, "Intestinal event segmentation for endoluminal video analysis," in *Proc. of IEEE International Conference on Image Processing (ICIP)*. IEEE, 2014, pp. 3592–3596.
- [294] J. Berens, M. Mackiewicz, and D. Bell, "Stomach, intestine, and colon tissue discriminators for wireless capsule endoscopy images," in *Medical Imaging*. International Society for Optics and Photonics, 2005, pp. 283–290.
- [295] Y. Yuan and M. Q. H. Meng, "Hierarchical key frame extraction for wireless capsule endoscopy video based on the saliency map," *International Journal of Mechatronics and Automation*, vol. 4, no. 4, pp. 259–268, 2014.
- [296] S. Tsevas, D. K. Iakovidis, D. Maroulis, and E. Pavlakis, "Automatic frame reduction of Wireless Capsule Endoscopy video," in *2008 8th IEEE International Conference on Bioinformatics and BioEngineering*. IEEE, 2008, pp. 1–6.
- [297] E. Spyrou and D. K. Iakovidis, "Homography-based orientation estimation for capsule endoscopy tracking," in *2012 IEEE International Conference on Imaging Systems and Techniques Proc.* IEEE, 2012, pp. 101–105.
- [298] E. Spyrou, D. Diamantis, and D. K. Iakovidis, "Panoramic Visual Summaries for Efficient Reading of Capsule Endoscopy Videos," in *2013 8th International Workshop on Semantic and Social Media Adaptation and Personalization*. IEEE, 2013, pp. 41–46.
- [299] B. Li, C. Yang, T. Wang, G. Xu, Q. Zhang, and C. Hu, "Capsule Endoscopy Video Segmentation by Spectral Clustering," in *11th World Congress on Intelligent Control and Automation (WCICA)*. IEEE, 2014, pp. 976–979.
- [300] N. Bourbakis, "Detecting abnormal patterns in WCE images," in *Proc. 5th IEEE Symposium on Bioinformatics and Bioengineering (BIBE)*. IEEE, 2005, pp. 232–238.
- [301] Y. Cao, D. Liu, W. Tavanapong, J. Wong, J. Oh, and P. C. de Groen, "Computer-aided detection of diagnostic and therapeutic operations in colonoscopy videos," *Biomedical Engineering, IEEE transactions on*, vol. 54, no. 7, pp. 1268–79, 2007.
- [302] Y. Cao, D. Liu, W. Tavanapong, J. Wong, J. Oh, and P. C. de Groen, "Automatic classification of images with appendiceal orifice in colonoscopy videos," in *Proc. Annual International Conference of IEEE Engineering in Medicine and Biology Society (EMBS)*, vol. 1. IEEE, 2006, pp. 2349–2352.
- [303] J. Chen, Y. Wang, and Y. X. Zou, "An adaptive redundant image elimination for Wireless Capsule Endoscopy review based on temporal correlation and color-texture feature similarity," in *Digital Signal Processing (DSP), 2015 IEEE International Conference on*. IEEE, 2015, pp. 735–739.
- [304] Y.-j. Chen, W. Yasen, J. Lee, D. Lee, and Y. Kim, "Developing assessment system for wireless capsule endoscopy videos based on event detection," in *Proc. of SPIE*, vol. 7260. International Society for Optics and Photonics, 2009, pp. 72 601G–72 601G–11.
- [305] O. Dunaeva, H. Edelsbrunner, A. Lukyanov, M. Machin, and D. Malkova, "The Classification of Endoscopy Images with Persistent Homology," in *Proc. 16th International Symposium on Symbolic and Numeric Algorithms for Scientific Computing*. IEEE, 2014, pp. 565–570.
- [306] Y. Fu, H. Liu, Y. Cheng, T. Yan, T. Li, and M.-H. Meng, "Key-frame selection in WCE video based on shot detection," in *Proc. World Congress on Intelligent Control and Automation (WCICA)*. IEEE, 2012, pp. 5030–5034.
- [307] G. Gallo and A. Torrisi, "Random forests based WCE frames classification," in *Proc. 25th IEEE International Symposium on Computer-Based Medical Systems (CBMS)*. IEEE, 2012, pp. 1–6.
- [308] V. U. Hai, T. Echigo, R. Sagawa, Y. Keiko, M. Shiba, K. Higuchi, T. Arakawa, and Y. Yasushi, "Controlling the display of capsule endoscopy video for diagnostic assistance," *IEICE transactions on information and systems*, vol. 92, no. 3, pp. 512–528, 2009.
- [309] T. M. Htwe, C. K. Poh, L. Li, J. Liu, E. H. Ong, and K. Y. Ho, "Vision-based techniques for efficient Wireless Capsule Endoscopy examination," in *2011 Defense Science Research Conference and Expo (DSR)*. IEEE, 2011, pp. 1–4.
- [310] J. S. Huo, Y. X. Zou, and L. Li, "An advanced WCE video summary using relation matrix rank," in *Proc. of 2012 IEEE-EMBS International Conference on Biomedical and Health Informatics*. IEEE, 2012, pp. 675–678.
- [311] S. Hwang, "Automatic content analysis of endoscopy video (Endoscopic Multimedia Information System)," Ph.D. dissertation, The University of Texas at Arlington, 2007.
- [312] S. Hwang, J. Oh, W. Tavanapong, J. Wong, and P. C. de Groen, "Stool detection in colonoscopy videos," in *Proc. Annual International Conference of IEEE Engineering in Medicine and Biology Society (EMBS)*, vol. 2008. IEEE, 2008, pp. 3004–7.
- [313] H.-G. Lee, M.-K. Choi, B.-S. Shin, and S.-C. Lee, "Reducing redundancy in wireless capsule endoscopy videos," *Computers in Biology and Medicine*, vol. 43, no. 6, pp. 670–82, 2013.
- [314] J. Lee, J. Oh, S. K. Shah, X. Yuan, and S. J. Tang, "Automatic classification of digestive organs in wireless capsule endoscopy videos," in *Proc. ACM symposium on Applied computing (SAC)*. ACM, 2007, pp. 1041–1045.
- [315] B. Li, H. Jin, C. Yang, and G. Xu, "A novel color textural feature towards capsule endoscopy video summary," in *Information and Au-*

- tomation, 2015 *IEEE International Conference on*. IEEE, 2015, pp. 766–769.
- [316] A. Klepaczko and P. Szczypiński, “Automated segmentation of endoscopic images based on local shape-adaptive filtering and color descriptors,” in *Advanced Concepts for Intelligent Vision Systems*. Springer, 2010, vol. 6474 LNCS, pp. 245–254.
- [317] F. Riaz, F. B. Silva, M. D. Ribeiro, and M. T. Coimbra, “Impact of Visual Features on the Segmentation of Gastroenterology Images Using Normalized Cuts,” *Biomedical Engineering, IEEE Transactions on*, vol. 60, no. 5, pp. 1191–1201, 2013.
- [318] M. Suenaga, Y. Fujita, S. Hashimoto, T. Shuji, I. Sakaida, and Y. Hamamoto, “A Method of Bubble Removal for Computer-Assisted Diagnosis of Capsule Endoscopic Images,” in *Modern Advances in Applied Intelligence*. Springer, 2014, pp. 228–233.
- [319] M. Chowdhury and M. K. Kundu, “Endoscopic Image Retrieval System Using Multi-scale Image Features,” in *Proc. 2nd International Conference on Perception and Machine Intelligence*. ACM, 2015, pp. 64–70.
- [320] J. Kalpathy-Cramer, “Classification and retrieval of endoscopic images from the clinical outcomes research initiative (CORI) collection,” Master’s thesis, Oregon Health and Science University, 2009.
- [321] P. C. Khun, Z. Zhuo, L. Z. Yang, L. Liyuan, and L. Jiang, “Feature selection and classification for Wireless Capsule Endoscopic frames,” in *Proc. International Conference on Biomedical and Pharmaceutical Engineering*. IEEE, 2009, pp. 1–6.
- [322] R. Kumar, P. Rjan, S. Bejakovic, S. Seshamani, and G. Mullin, “Learning Disease Severity for Capsule Endoscopy,” in *Proc. IEEE International Symposium on Biomedical Imaging: From Nano to Macro (ISBI)*. IEEE, 2009, pp. 1314–1317.
- [323] R. Kwitt, N. Rasiwasia, N. Vasconcelos, A. Uhl, M. Häfner, and F. Wrba, “Learning pit pattern concepts for gastroenterological training,” in *Proc. International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*. Springer, 2011, vol. 6893, pp. 280–287.
- [324] R. Kwitt, A. Uhl, M. Häfner, A. Gangl, F. Wrba, and A. Vecsei, “Predicting the histology of colorectal lesions in a probabilistic framework,” in *Proc. IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops*. IEEE, 2010, pp. 103–110.
- [325] R. Kwitt, N. Vasconcelos, N. Rasiwasia, A. Uhl, B. Davis, M. Häfner, and F. Wrba, “Endoscopic image analysis in semantic space,” *Medical Image Analysis*, vol. 16, no. 7, pp. 1415–1422, 2012.
- [326] D. Liu, Y. Cao, K.-H. Kim, S. Stanek, B. Doungratanaex-Chai, K. Lin, W. Tavanapong, J. Wong, J. Ahn, and P. C. de Groen, “Arthemis: annotation software in an integrated capturing and analysis system for colonoscopy,” *Computer Methods and Programs in Biomedicine*, vol. 88, no. 2, pp. 152–63, 2007.
- [327] T. Tamaki, J. Yoshimuta, M. Kawakami, B. Raytchev, K. Kaneda, S. Yoshida, Y. Takemura, K. Onji, R. Miyaki, and S. Tanaka, “Computer-aided colorectal tumor classification in NBI endoscopy: Using local features,” *Medical Image Analysis*, vol. 17, no. 1, pp. 78–100, 2013.
- [328] G. Yang, Y. Yin, and H. Man, “Biomedical Image Analysis on Wireless Capsule Endoscopy Images and Videos,” in *Selected Topics in Micro/Nano-robotics for Biomedical Applications*. Springer, 2013, pp. 23–43.
- [329] M. Mackiewicz, J. Berens, M. Fisher, and D. Bell, “Colour and texture based gastrointestinal tissue discrimination,” in *Acoustics, Speech and Signal Processing, 2006. ICASSP 2006 Proc.* 2006 *IEEE International Conference on*, vol. 2. IEEE, 2006, pp. II–II.
- [330] M. Biswas, “Hilbert Huang Transform Based Video Analysis for Detecting Various Colon Diseases using Composite Similarity Measure,” Master’s thesis, Jadavpur University, 2014.
- [331] A. F. Constantinescu, M. Ionescu, I. Rogoveanu, M. E. Ciurea, C. T. Streba, V. F. Iovanescu, S. A. Artene, and C. C. Vere, “Analysis of Wireless Capsule Endoscopy Images using Local Binary Patterns,” *Applied Medical Informatics*, vol. 36, no. 2, pp. 31–42, 2015.
- [332] Y. Cong, S. Wang, J. Liu, J. Cao, Y. Yang, and J. Luo, “Deep sparse feature selection for computer aided endoscopy diagnosis,” *Pattern Recognition*, vol. 48, no. 3, pp. 907–917, 2015.
- [333] M. Boulougoura, E. Wadge, V. S. Kodogiannis, and H. S. Chowdrey, “Intelligent systems for computer-assisted clinical endoscopic image analysis,” in *Proc. 2nd International Conference on Biomedical Engineering*. ACTA Press, 2004, pp. 405–408.
- [334] A. M. C. de Sousa, “Analysis of colour and texture features of vital magnification-endoscopy images for computer diagnosis of precancerous and cancer lesions,” Master’s thesis, Universidade do Porto, 2008.
- [335] M. Gadermayr and A. Uhl, “Degradation adaptive texture classification,” in *Proc. of IEEE International Conference on Image Processing (ICIP)*. IEEE, 2014, pp. 2759–2763.
- [336] M. Gadermayr, A. Uhl, and A. Vecsei, “Degradation Adaptive Texture Classification: An Extended Analysis Leads to a Different Perspective,” Universität Salzburg, Tech. Rep., 2015.
- [337] M. Gadermayr and A. Uhl, “Making Texture Descriptors Invariant to Blur,” Universität Salzburg, Tech. Rep. 2015-04, 2015.
- [338] M. Häfner, A. Uhl, A. Vecsei, G. Wimmer, and F. Wrba, “Complex Wavelet Transform variants and Discrete Cosine Transform for scale invariance in magnification-endoscopy image classification,” in *Proc. 10th IEEE International Conference on Information Technology and Applications in Biomedicine*, 2010, pp. 1–5.
- [339] M. Häfner, L. Brunauer, H. Payer, R. Resch, F. Wrba, A. Gangl, A. Vecsei, and A. Uhl, “Pit pattern classification of zoom-endoscopic colon images using DCT and FFT,” in *Proc. IEEE Symposium on Computer-Based Medical Systems (CBMS)*. IEEE, 2007, pp. 159–164.
- [340] M. Häfner, A. Gangl, M. Liedlgruber, A. Uhl, A. Vecsei, and F. Wrba, “Combining Gaussian Markov random fields with the discrete-wavelet transform for endoscopic image classification,” in *2009 16th International Conference on Digital Signal Processing*. IEEE, 2009, pp. 1–6.
- [341] M. Häfner, R. Kwitt, A. Uhl, A. Gangl, F. Wrba, and A. Vecsei, “Feature extraction from multi-directional multi-resolution image transformations for the classification of zoom-endoscopy images,” *Pattern Analysis and Applications*, vol. 12, no. 4, pp. 407–413, 2009.
- [342] M. Häfner, A. Gangl, M. Liedlgruber, A. Uhl, A. Vecsei, and F. Wrba, “Pit pattern classification using extended Local Binary Patterns,” in *2009 9th International Conference on Information Technology and Applications in Biomedicine*. IEEE, Nov 2009, pp. 1–4.
- [343] M. Häfner, M. Liedlgruber, S. Maimone, A. Uhl, F. Wrba, and Others, “Evaluation of cross-validation protocols for the classification of endoscopic images of colonic polyps,” in *Proc. 25th International Symposium on Computer-Based Medical Systems (CBMS)*. IEEE, 2012, pp. 1–6.
- [344] D. K. Iakovidis, D. E. Maroulis, and S. a. Karkanis, “An intelligent system for automatic detection of gastrointestinal adenomas in video endoscopy,” *Computers in biology and medicine*, vol. 36, no. 10, pp. 1084–103, Oct 2006.
- [345] A. Kage, M. Christian, and T. Wittenberg, “A Knowledge-based System for the Computer Assisted Diagnosis of Endoscopic Images,” in *Bildverarbeitung für die Medizin 2008*. Springer, 2008, pp. 272–276.
- [346] M. J. Kumara, “Automated real-time objects detection in colonoscopy videos for quality measurements,” Ph.D. dissertation, University of North Texas, 2013.
- [347] M. Häfner, A. Gangl, M. Liedlgruber, A. Uhl, F. Wrba, and Others, “Endoscopic image classification using edge-based features,” in *Proc. 20th International Conference on Pattern Recognition (ICPR)*. IEEE, 2010, pp. 2724–2727.
- [348] M. Häfner, A. Gangl, F. Wrba, K. Thonhauser, H. P. Schmidt, C. Kastinger, A. Uhl, and A. Vecsei, “Comparison of k-NN, SVM, and NN in pit pattern classification of zoom-endoscopic colon images using co-occurrence histograms,” in *Proc. 5th International Symposium on Image and Signal Processing and Analysis (ISPA)*. IEEE, 2007, pp. 516–521.
- [349] M. Häfner, S. Hegenbart, M. Liedlgruber, A. Uhl, A. Vecsei, and F. Wrba, “Optimized Selection of Weak Methods for the Classification of Endoscopic Images Using an Ensemble Classifier,” in *Proc. 7th International Symposium on Image and Signal Processing and Analysis (ISPA)*. IEEE, 2011, pp. 721–726.
- [350] M. Häfner, A. Gangl, M. Liedlgruber, A. Uhl, A. Vecsei, and F. Wrba, “Pit Pattern Classification Using Multichannel Features and Multi-classification,” *Handbook of Research on Advanced Techniques in Diagnostic Imaging and Biomedical Applications*, pp. 335–350, 2009.
- [351] M. Häfner, A. Gangl, and M. Liedlgruber, “Classification of endoscopic images using Delaunay triangulation-based edge features,” in *Image Analysis and Recognition*. Springer, 2010, pp. 131–140.
- [352] M. Häfner, R. Kwitt, A. Uhl, F. Wrba, A. Gangl, and A. Vecsei, “Computer-assisted pit-pattern classification in different wavelet domains for supporting dignity assessment of colonic polyps,” *Pattern Recognition*, vol. 42, no. 6, pp. 1180–1191, 2009.
- [353] M. Häfner, M. Liedlgruber, a. Uhl, a. Vecsei, and F. Wrba, “Color treatment in endoscopic image classification using multi-scale local color vector patterns,” *Medical Image Analysis*, vol. 16, no. 1, pp. 75–86, 2012.
- [354] M. Häfner, M. Liedlgruber, A. Uhl, and G. Wimmer, “Bridging the Resolution Gap between Endoscope Types for a Colonic Polyp Classi-

- cation,” in *2014 22nd International Conference on Pattern Recognition*. IEEE, 2014, pp. 2739–2744.
- [355] M. Häfner, M. Liedlgruber, A. Uhl, and G. Wimmer, “Evaluation of super-resolution methods in the context of colonic polyp classification,” in *Content-Based Multimedia Indexing (CBMI), 2014 12th International Workshop on*. IEEE, 2014, pp. 1–6.
- [356] M. Häfner, T. Tamaki, S. Tanaka, A. Uhl, G. Wimmer, and S. Yoshida, “Local fractal dimension based approaches for colonic polyp classification,” *Medical Image Analysis*, vol. 26, no. 1, pp. 92–107, Dec 2015.
- [357] A. Karargyris and N. Bourbakis, “Wireless capsule endoscopy and endoscopic imaging: A survey on various methodologies presented,” *Engineering in Medicine and Biology Magazine, IEEE*, vol. 29, no. 1, pp. 72–83, 2010.
- [358] M. Keuchel, N. Kurniawan, P. Baltes, D. Bandorski, and A. Koulaouzidis, “Quantitative measurements in capsule endoscopy,” *Computers in biology and medicine*, 2015.
- [359] R. Kumar, Q. Zhao, S. Seshamani, G. Mullin, G. Hager, and T. Dasopoulou, “Assessment of crohn’s disease lesions in wireless capsule endoscopy images,” *Biomedical Engineering, IEEE Transactions on*, vol. 59, no. 2, pp. 355–362, 2012.
- [360] I. Laranjo, J. Braga, D. Assunção, C. Rolanda, L. Lopes, J. Correia-pinto, and V. Alves, “Video Processing Architecture: A Solution for Endoscopic Procedures Results,” in *Ambient Intelligence-Software and Applications*. Springer, 2014, vol. 291, pp. 117–125.
- [361] M. Liedlgruber and A. Uhl, “Computer-Aided Decision Support Systems for Endoscopy in the Gastrointestinal Tract: A Review,” *IEEE Reviews in Biomedical Engineering*, vol. 4, pp. 73–88, 2011.
- [362] M. Liedlgruber and A. Uhl, *Predicting Pathology in Medical Decision Support Systems in Endoscopy of the Gastrointestinal Tract*. INTECH Open Access Publisher, 2011.
- [363] M. Mackiewicz, *Capsule Endoscopy - State of the Technology and Computer Vision Tools After the First Decade*. INTECH Open Access Publisher, 2011.
- [364] D. E. Maroulis, D. K. Iakovidis, S. a. Karkanis, and D. a. Kararas, “CoLD: A versatile detection system for colorectal lesions in endoscopy video-frames,” *Computer Methods and Programs in Biomedicine*, vol. 70, no. 2, pp. 151–166, 2003.
- [365] D. Mikhaylov, A. Starikovskiy, V. Konev, A. Grigorenko, and S. Larisa, “Review of Software for Automated Analysis of Digestive Tract Images,” *Biosciences Biotechnology Research Asia*, vol. 11, no. 3, pp. 1109–1114, 2014.
- [366] B. Wang and D. Yang, “Computer-Assisted Diagnosis of Digestive Endoscopic Images Based on Bayesian Theory,” in *2009 International Conference on Information Engineering and Computer Science*. IEEE, 2009, pp. 1–4.
- [367] Y. M. Yacob, H. Amylia, M. Sakim, N. Baharudin, L. Y. Yeh, N. Ashidi, and M. Isa, “A Survey on Medical Digital Imaging of Endoscopic Gastritis,” in *IEEE TENCON 2009 : IEEE Region 10 Conference*. IEEE, 2009, pp. 1–6.
- [368] M. M. Zheng, S. Krishnan, and M. P. Tjoa, “A fusion-based clinical decision support for disease diagnosis from endoscopic images,” *Computers in biology and medicine*, vol. 35, no. 3, pp. 259–74, 2005.