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Small intestine bleeding detection using color threshold and morphological operation in WCE images

A. Al. Mamun[1], M. S. Hossain[2], P. P. Em[3], A. Tahabilder[4], R. Sultana[5], M. A. Islam[6]
[1,3]Faculty of Engineering and Technology, Multimedia University, Melaka, Malaysia
[2,6]Department of EEE, Pabna University of Science and Technology, Pabna, Bangladesh
[4]Department of Electrical & Computer Engineering, Stevens Institute of Technology, Hoboken, USA
[5]Department of Computer Science and Engineering, University of Colorado Denver, Denver, USA

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ABSTRACT

Wireless capsule endoscopy (WCE) is a significant modern technique for observing the whole gastroenterological tract to diagnose various diseases like bleeding, ulcer, tumor, Crohn's disease, and polyps in a non-invasive manner. However, it will make a substantial onus for physicians like human oversight errors with time consumption for manual checking of a vast amount of image frames. These problems motivate the researchers to employ a computer-aided system to classify the particular information from the image frames. Therefore, a computer-aided system based on the color threshold and morphological operation has been proposed in this research to recognize specified bleeding images from the WCE. Besides, A unique classifier, quadratic support vector machine (QSVM) has been employed for classifying the bleeding and non-bleeding images with the statistical feature vector in HSV color space. After extensive experiments on clinical data, 95.8% accuracy, 95% sensitivity, 97% specificity, 80% precision, 99% negative predicted value and 85% F1 score has been achieved, which outperforms some of the existing methods in this regard. It is expected that this methodology would bring a significant contribution to the WCE technology.

Corresponding Author:

Abdullah Al Mamun
Faculty of Engineering and Technology
Multimedia University
Ayer Keroh, Melaka-7540, Malaysia
Email: mamun130203@gmail.com

1. INTRODUCTION

In recent years, the diseases related to the gastrointestinal tract (GI), especially in the esophagus, stomach, small intestine and large intestine take the attention of the researchers because of its lousy impact around the world. It has been found from surveillance that approximately 27.8% of people in South Asia and around 1.6 mm (million) American people are affected and died of inflammatory bowel disease and about 80 thousand [1]. So, it has become an important task to develop the curing technique for GI tract problems. The diagnostic procedure for these diseases is the conventional fiber-optic endoscopy, which causes much panic for the peasants. Along with this, it cannot checkup the whole area entirely, especially the small intestine [2]. To solve this challenge WCE technique shows a tremendous revolution by which physicians can detect more abnormalities in the GI tract along with bleeding. In WCE technology, there has a capsule-shaped device with a camera, light source, wireless transmitter and battery. It also needs some associated devices such as image sensors, image receiver and computer with bleeding detecting tools. This device is swallowed to the patient that passes through the GI tract and capture videos. Approximately eight hours are needed for the whole procedure, and this video is converted into image frames, which is not possible for clinicians to check these images manually. So, the applied computer-based system removes the burden of the physicians and makes their work easy to identify another disease along with bleeding at the same time [3].

2. RELATIVE WORKS

Bleeding detection is very much vital from the clinical perspective due to many of the GI tract disease recognition depends on it [4]. Distinct types of computer-aided systems have already been introduced into WCE images to deduce the burden of the physicians for detecting the bleeding. However, these techniques provided unsatisfactory results in terms of sensitivity and specificity, such as Suspected Blood Indicator [5]. Initially, a framework was designed to detect bleeding portion in which the specificity and sensitivity were only 41.8% and 21.5%. A superpixel technique has been applied by Sivakumar *et al.* [6] with a Naive Bayes classifier to detect the bleeding region accurately. However, the model has been trained only two statistical features and did not validate with the other exiting techniques. The information loss can be reduced up to a significance level by using multiple random training datasets and achieved higher specificity and sensitivity by applying the support vector machine.

Konstantin *et al.* have introduced a bleeding detection technique utilizing the texture and color features that would provide the complete color information. Nevertheless, the color information technology provides lower performance results compared to the other existing methods [7]. The frequency spectrum of characteristics pattern is used based on normalized gray level co-occurrence matrix and also achieved a satisfactory bleeding detection rate [8]. A unique two-fold system is introduced to detect the bleeding portioning in which K-means clustering and SVM classifier has been applied to extract the cluster center and distinguish the bleeding images correspondently [9]. A changeable color domain has been implemented instead of the RGB color model to reduce the computational time. Besides, the support vector machine has been applied to the statistical features depending on higher and lower values to classify the bleeding and non-bleeding image efficiently [4].

In [10], the authors extracted different color features from the images by employing the histogram technique, and SVM classifier applied to distinct images. Authors proposed in [11] a compound model named Y.I/Q to extract the information about the chrominance and luminance for acquiring the region of interest of the images and the SVM classifier technique employed for a satisfactory result. In [12], authors formed a pixel intensity ration of R/G (Red/Green) from the RGB color model to achieve different statistical features and K- nearest neighbor classifier used for classification. Authors employed intensity fluctuation of the pixels in the RGB color model with statistical characteristics analysis in [13]. Though these techniques have done tremendous work on bleeding detection from WCE images, these still have the limitation of computational complexity and lower performance results. Color threshold techniques on different color spaces have been applied for detecting different abnormalities. However, it couldn't distinguish the informative portion from the background for all the images [2, 3, 5, 14-18].

In this paper, a unique technique for accurately bleeding identification of WCE images in HSV color space has been proposed. First of all, the video footage has been converted into the image frame and remove the non-informative portion using some pre-processing techniques. After the process of delusion removal and morphological operations, some statistical features (e.g., mean, standard deviation) are extracted from the output images to have the feature vector. This feature vector has been used in a QSVM classifier to detect the bleeding and non-bleeding images. Our proposed method has tested on the publicly available clinical dataset, and satisfactory bleeding detection results are obtained.

3. RESEARCH METHOD

In the proposed method, color threshold and morphological operation-based technique has been applied for bleeding detection. The pictorial representation of the whole proposed approach has been shown in Figure 1. An annotated bleeding and non-bleeding dataset have been created for classifying the bleeding images from the non-bleeding image. The annotated dataset can be made by converting the video clip from WCE like PillCam*SB into the images. Around 2393, annotated bleeding and non-bleeding images have been used to analyze the proposed method, which is available in [19]. In [20], they offer a bleeding detection technique using 2300 WCE images, though 2393 images have been used in the proposed method.

3.1. Color threshold

Now the important part is to select the informative portion or object from the image and remove the other non-informative part from the picture, which provides a more accurate and efficient result in feature extraction and classification. One of the steps for the task is the color threshold, which removes the non-bleeding area from the images and stores the information of the remaining required bleeding portion. We have distributed the image into three color channels and give the color threshold for different values for the corresponding channels. Figure 2 shows the color threshold image, still improvement is necessary on that image, and the following sequential process does this.

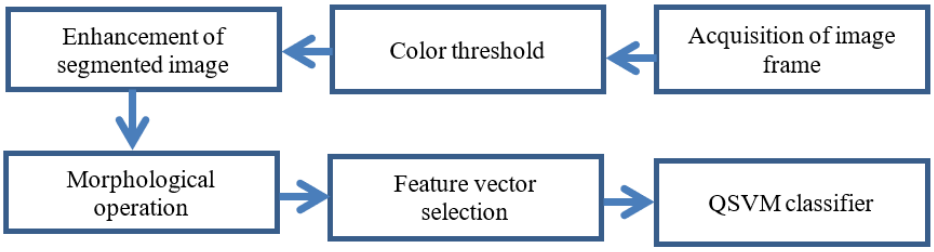


Figure 1. Overall representation of the proposed method

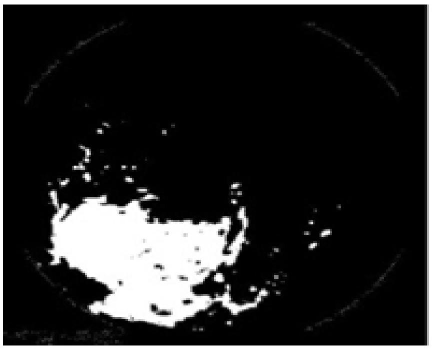


Figure 2. Color threshold image

3.2. Enhancement of segmented image

The segmented image is a binary image that stands for 1 and 0 and describes for the white and black portion of the image respectfully. After the threshold, there are many noises, and unwanted parts of holes exist in the image. Here holes represent the pixels of background which are unable to fill from the edge corner of the images in the background, which has been fixed by Soille's method. Since the first time, some unwanted portions still exist, we have applied this method twice times for more clarified results. The output image has been sharped using unsharp masking.

3.3. Fileting and morphological operation

A multidimensional image N-D filter has been employed to reduce the probability of overflows elements from a specific range of values and obtain round values. It also has the capability of comparing it with the target value. A 2-D median filter has been used for getting the detailed result on every output pixel to obtain the median values of corresponding neighborhood pixels of the input image. Before applying the watershed transform, a level is fixed to reduce the variance of interclass of white and black pixels by Otsu's method. The process of water shade transform will revert with a leveled matrix which distinguishes the water region of that image. It will detect the "catchment basins" or "watershed ridge lines" by considering the image as the surface in which slight pixels describe high superiority and reverse for the dark pixels. This is done by using Bradley's method, which provides the analogous output of the input image by utilizing 1/8th times of the size of the neighborhood image. Fernand Meyer technique has been employed to obtain the water shade regions of the given image. If i is the output of the technique, then $i \geq 0$. When, i=0; Absence of watershed region, i=1; Initial watershed region,i=2; Second watershed region and so on.

The informative portion of images has been extracted, which is completely separated from the background as well to the other object if it presents. It's a very effective way to distinguish the specified object from the specified background of the image and also from one object to another [21]. After completely separating the informative portion of that image from the background as well to the different object, Morphology is applied. It is the procedure to process the image following shape. This procedure employs the structural element from strewing, which we applied to that particular image and will provide the image with analogous size. In this operation, every pixel values from the output image will compare with the pixel values of the given image associated with the neighbors [22]. By selecting an appropriate model of shape and size of the neighbors, we have characterized the morphological operation is very susceptible to the given image in a considerable way. In the case of this operation, we have used dilation and erosion with the structural element from strewing. Here the dilation and erosion appended and eliminated the pixels to the corresponding boundaries of the object. Depending on the proper model of shape and size of the structural elements the number of pixels is appended and eliminated. After completing the morphological operation, we got the appropriate informative portion from the image and seem to be more accurate as shown in Figure 3.

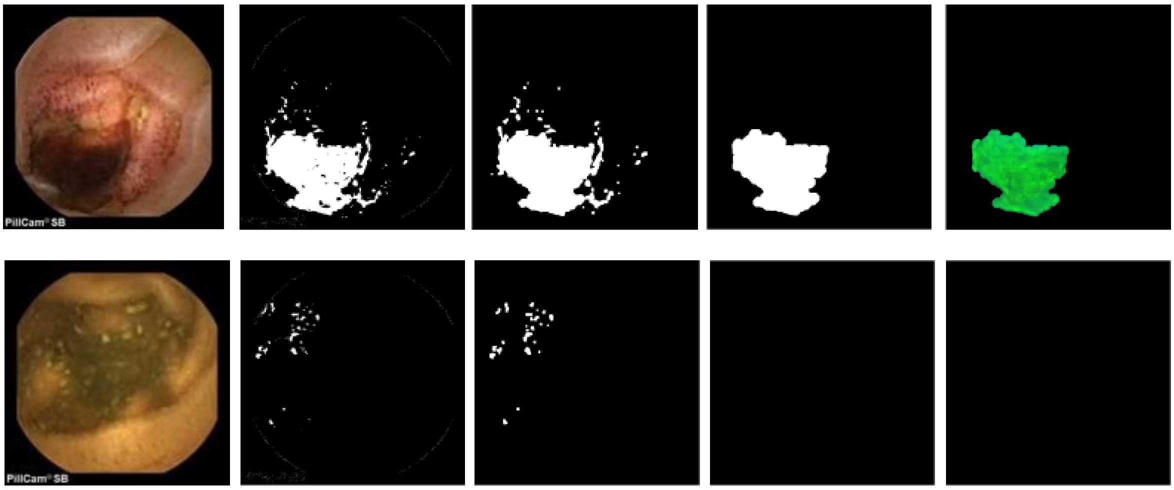
In the case of dilation of S and T,

$$S \oplus T = \left\{ z \,\middle|\, (\hat{Q})_z \cap S \neq \emptyset \right\} \tag{1}$$

Again, in the case of erosion of S and T,

$$S \ominus T = \left\{ z \,\middle|\, (\hat{Q})_z \subseteq S \right\} \tag{2}$$

Where, $\hat{Q}$ refers to the repercussions of $\hat{Q}$s structure element



(a) (b) (c) (d) (e)

Figure 3. The output of the entire process: (a) Bleeding and non-bleeding image (top and bottom respectfully), (b) threshold image, (c) enhanced segmented image, (d) after the morphological operation, (e) HSV color space for the extracted image.

3.4. Feature selection for bleeding detection

The process of feature extraction can be referred to as the dimensional retrenchment that can be represented as a particular section of images efficiently in a specified vector of features. The proposed method used distinct statistical features like mean, mode, variance, entropy, skewness maxima, and moment to extract the features and make proper calculations from the segmented image. These characterized features are extracted from the proposed HSV color model since the HSV color model provides the best possible result in the proposed methodology.

3.5. QSVM classifier

In the proposed technique, the support vector machine (SVM) has been used for classification. SVM is a classifier technique using the nonparametric arrangement in kernel function. We use a quadratic SVM (QSVM) classifier technique for separating bleeding and non-bleeding portion. Say, we have considered n training data b_i, $b_i \in \mathbb{R}^N$ for i=1, n each either in bleeding or non-bleeding. Then used as a separating rule:

$$\omega^T x \geq \gamma \tag{3}$$

Where, $x \in \mathbb{R}^N$ is a variable with$\omega \in \mathbb{R}^N$, $\gamma \in \mathbb{R}$ is the classifier parameters.

Here, we have used kernel function denoted by$K(x_{bl}, x_{nbl}))$ where x_{bl} means bleeding, and x_{nbl} means non-bleeding, $K(x_{bl}, x_{nbl}) = (x_{bl}.x_{nbl})^d$; Here d is the degree of the polynomial. Now, to get ω and γ from as (4),

$$\min_{\omega\in\mathbb{R}^N, \gamma\in\mathbb{R}, y\in\mathbb{R}_+^n} \frac{1}{2} y^T D[K(x_{bl}, x_{nbl})K(x_{bl}, x_{nbl})]Dy - Ce^T y \quad (4)$$

Where,

$$\omega = y^T D[K(x_{bl}, x_{nbl})K(x_{bl}, x_{nbl})]Dy$$
$$\gamma = -e^T Dy$$

For the classification, we have used a 25% holdout validation technique to split these samples into training and testing data. 75% of the image data were in the training dataset and 25% were in the testing dataset. After applying QSVM classifier in the feature vector, the bleeding and non-bleeding images have been classified.

4. RESULTS AND DISCUSSIONS

In case of bleeding detection commonly faced four possible events that are shown below:
- True positive (*TP*); Actually, bleeding images
- True negative (*TN*); Actually, non-bleeding images
- False positive (*FP*); Actually, bleeding but detect as non-bleeding images
- False negative (*FN*); Actually, non-bleeding but recognize as bleeding images

The only accuracy does not provide the reliably of a method. Also needed some other parameters such as sensitivity, specificity, precision, F1 score, and negative predicted value. to justify the performance of a technique. The proposed method has achieved the best possible result of accuracy 95.8%, sensitivity 95%, specificity 97%, precision 80%, negative predicted value 99% and F1 score 86.9%, depicted in Figure 4. Again, Figure 5 shows the performances of the proposed method in four different color spaces like HSV, RGB, L*a*b*, and YCbCr. It provides evidence that HSV color space provides the best possible result except for precision, higher in RGB color space. But considering the higher values of other performance parameters, HSV color space has been proposed. Furthermore, Figure 6 shows the performance of the proposed method in four distinct types of classifiers, such as Fine Gaussian SVM, WKNN, CSVM, and QSVM, for selecting the proper classifier. By comparing these four classifiers, QSVM is the most suitable classifier for bleeding detection, considering the proposed method proving higher performance results.

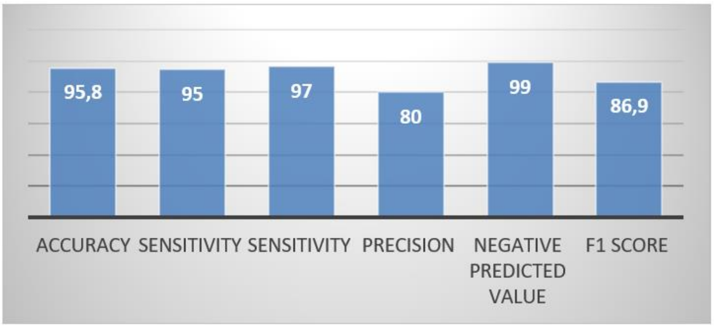


Figure 4. Overall performance of the proposed method

In the proposed technique, three steps have been applied, like (1) Color threshold, (2) Enhancement of segmented images and (3) Filtering and morphological operation before feature extraction. The performance of the proposed method has gradually increased in consecutive these three steps, which provide the worthiness of the three stages. The performance in the successive three steps has been shown in Figure 7 in which 1, 2 and 3 represent the corresponding steps, and the proposed method has achieved higher performance in the last phase of filtering and morphological operation.

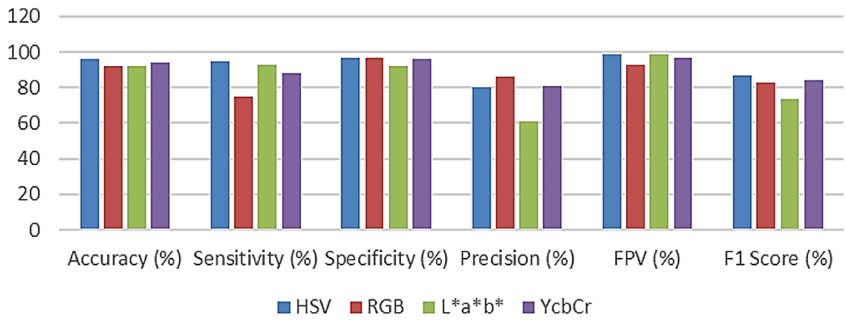


Figure 5. Performance result of the proposed method by varying distinct color models

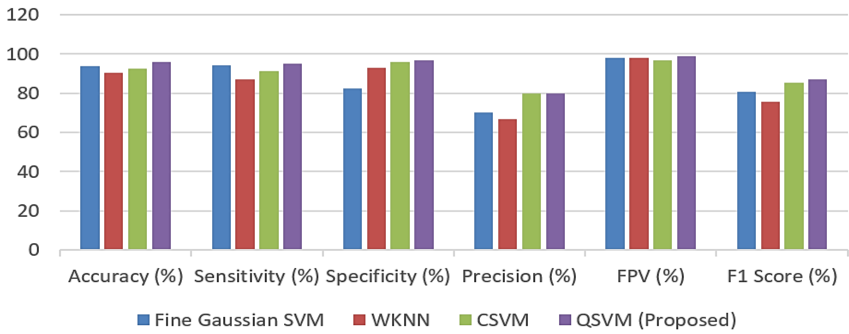


Figure 6. Performance result of the proposed method by varying distinct classifiers

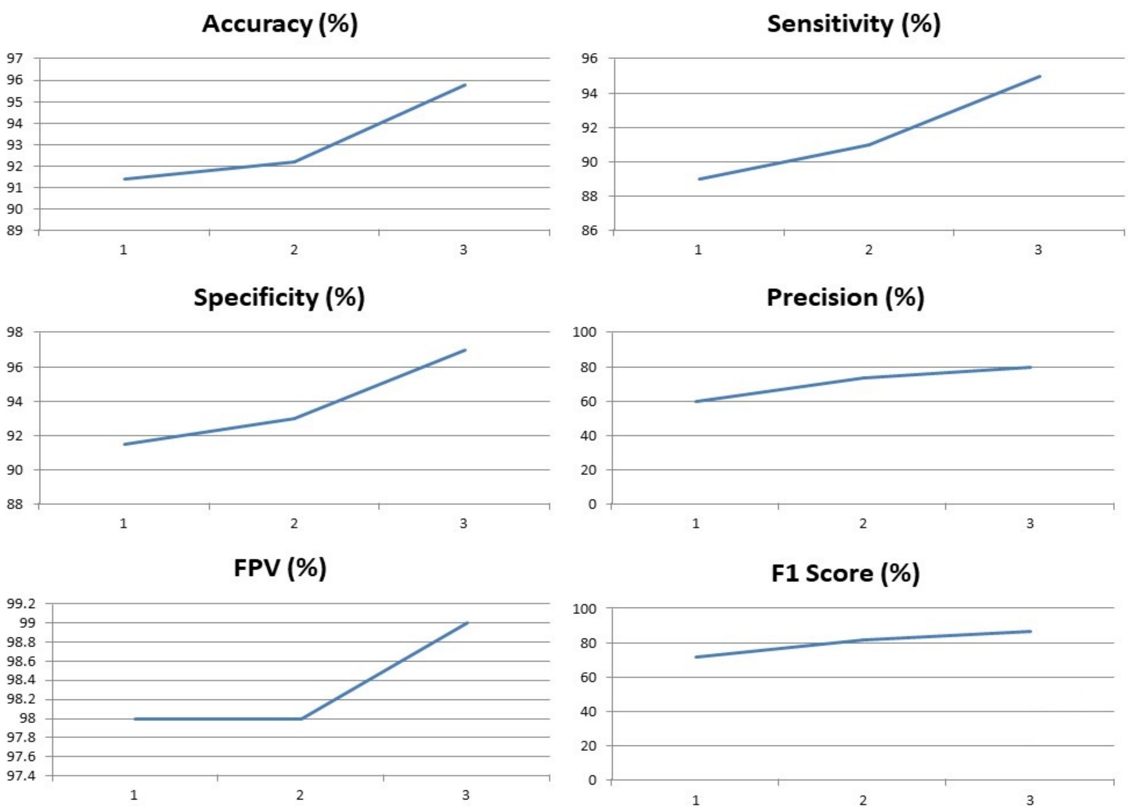


Figure 7. Performance results in three consecutive steps of the proposed method

Though revolutionary works have been implemented for detecting the bleeding portion, the proposed method is unique and also enriches the performance of this research field. A comparability study between the existing methods and the proposed method are presented in 1. From Table 1, it is visualized that the proposed technique is an improved edition of the bleeding detection research field in terms of accuracy and sensitivity compared with the existing work. Though Kundu *et al.* [20] examined 2300 color images from WCE for evaluating their bleeding detection algorithm, 2393 images have been examined in this proposed method, which is available in [23]. In addition, this proposed method also analysis with some other additional performance parameters like precision, F1 score, and negative-predicted value. In a nutshell, the proposed method is an accurate model of bleeding detection.

Table 1. Performance comparison with distinct color models

Methods	Accuracy	Sensitivity	Specificity
Uniform LBP [5]	91.5	79.25	94.56
Twofold System [9]	95.75	92	96.5
Binary feature vector [24]	91	93.12	88.39
Supervised learning technique [25]	90.92	-	-
Proposed method	**95.8**	**95**	**97**

Finally, we want to say that the proposed technique for bleeding detection provides the outperforms to others. In [20], they offer a bleeding detection technique using 2300 WCE images, but we have used 2393, available on the website [26]. The clarification of the specified segmentation technique or processing is also possible for giving more reliability to our proposed method. The comparison between our proposed method and the existing methods [5, 9, 24, 25] are shown in Table 1.

5. CONCLUSION

A unique method has been proposed in this research article in which the color threshold and morphological operation have been applied to detect the bleeding in WCE images. Initially, the color threshold images have been enhanced to enlighten the informative portion in the image frames. After that, we apply the morphological operation to purify the actual bleeding portion in those images. Finally, the proposed method has achieved accuracy 95.8%, sensitivity 95%, specificity 97%, precision 80%, negative predicted value 99% and F1 score 86.9% by examined the QSVM classifier from statistical feature vector with 25% holdout validation, which outperforms some of the existing research of bleeding detection. It is optimistic about having a significant impact on this research output in the bleeding detection technique. The future plane is to improvise more advanced features and classifiers to identify the bleeding portion more efficiently.

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BIOGRAPHIES OF AUTHORS

Abdullah Al Mamun has received a B.Sc. degree in Electrical and Electronic Engineering from Pabna University of Science and Technology in 2018. Now he is pursuing M.Eng.Sc.at Multimedia University (MMU) in the Faculty of Engineering and Technology since 2019. He is also working as a lecturer (on study leave) since November 2019 in EEE at Feni University, Feni, Bangladesh. His research interest includes computer vision; image processing, signal processing, deep learning and machine learning.

Md. Sohag Hossain has received a B.Sc. degree in Electrical and Electronic Engineering from Pabna University of Science and Technology in 2018. His research interest includes computer vision, image processing, signal processing, deep learning and machine learning.

Em Poh Ping is currently a lecturer at the Faculty of Engineering and Technology, Multimedia University. Poh Ping researches vehicle safety, data fusion, fuzzy control, and image processing. His current project is "lane departure estimation using vision and vehicle dynamical's state."

Anik Tahabilder is pursuing his Ph.D. at the Department of Electrical & Computer Engineering of the Stevens Institute of Technology, Hoboken, NJ-07307, USA. He got his MST degree from Western Carolina University, Cullowhee, NC-28723, USA. He also earned a B.Sc. degree in Electrical and Electronic Engineering from Pabna University of Science and Technology, Pabna-6600, Bangladesh. His research interest includes computer vision, machine learning, deep learning, and robotics.

Rumana Sultana has completed Bachelor of Science in Computer Science and Engineering from International Islamic University, Bangladesh. She also got an MST degree from Western Carolina University, USA. She is now enrolling in a PHD program in Computer Science and Information Systems at the University of Colorado Denver. Her research interest includes image processing, computer vision, AI with reinforcement learning, machine learning and deep leaning.

Md. Ariful Islam has received a B.Sc. degree in Electrical and Electronic Engineering from Pabna University of Science and Technology in 2016. Now he is pursuing M.Eng.Sc. at Rajshahi University of Engineering and Technology. His research interest includes EEG, image processing, signal processing, machine learning and deep learning.