μ-Mosaicing and Thermo-Mosaicing using Image In-painting

Amar K. Bendale
Department of E&TC
GF's Godavari College of Engg.
Jalgaon (India)

Dattatray A. Patil
Department of E&TC
GF's Godavari College of Engg.
Jalgaon (India)

Kantilal P. Rane
Department of E&TC
GF's Godavari College of Engg.
Jalgaon (India)

ABSTRACT
Microscopy has enormous applications in both medical and non-medical fields. This has gained interest of many researchers in the field of digital image processing to develop algorithms and applications helping in improving their observation and analysis. Here, novel method called '*μ-Mosaicing*' (read as Micro-Mosaicing) is introduced to create mosaics of microscopic images from a video sequence to obtain large view, high resolution images of specimen. A thermal camera forms images by sensing the infrared radiations from an object. High resolution thermal images can be used to determine temperatures in detailed thermal analysis. However, the cost of thermal camera increases with their resolution. While, thermo-graphy plays an important role in the diagnosis of various diseases, high resolution large field of view images will be certainly helpful in diagnosis and treatment. So a new approach to create mosaics of thermal images from video sequence, called '*Thermo-Mosaicing*', is proposed which can find wide applications in medical field. Both, μ-Mosaicing and Thermo-Mosaicing employ Key Frame Selection Algorithm, Image Matching using Normalized Cross Correlation (NCC), Image Stitching using 3-point Mask Blending Algorithm and Image In-painting.

General Terms
Image Mosaicing; Image Stitching; Microscopic Image Processing; Thermal Image Processing

Keywords
Image Mosaicing; Image Stitching; Key Frame Selection; Microscopic Image Mosaicing; Micro-mosaicing; Thermo-mosaicing and Thermal Image Mosaicing

1. INTRODUCTION
Image Mosaicing is a technique in which very big and high resolution image is obtained using a combination of two or more images. Since the field of view of camera is smaller than that of human eyes, it is not possible to obtain high resolution image having large field of view in single shot. Hence to obtain a high resolution image of large field of view, it is required to get different shots of the scene and combine them into a single image [1]. Image stitching, a specialized form of image mosaicing is used to make panoramic images. A process of generating one panoramic image from a series of smaller, overlapped images is known as panoramic image stitching [2]. Image mosaicing has been very popular with vast studies made by many people. Various techniques have evolved to perform the task of mosaicing and the technology has so progressed that mosaicing or creation of panoramic images is included as feature in many imaging devices or the allied software. The steps involved in image mosaicing are 1) image acquisition, 2) image preprocessing, 3) image registration and 4) image merging.

Image mosaicing has found many applications including consumer, industrial, medical, surveillance and monitoring and almost every field that involves observation and analysis using digital imaging since the mosaic image provides a large field of view with high resolution as compared to a normal image. In this paper, specifically, medical applications of image mosaicing and in particular, mosaicing of microscopic images as well as mosaicing of thermal images are considered. The following two subsections give brief information about microscopic image mosaicing and thermal image mosaicing.

1.1 Microscopic Image Mosaicing
Virtual microscopy [3] has been emerged as the main application of microscopic image mosaicing since digital samples do not degrade over time. Digital samples can be easily transmitted to many sites, can be easily browsed, navigated and annotated and in addition are free from risk of breakage, loss or contamination during transport.

Vignetting has been a problem in acquiring microscopic images and causes the images to appear bright at the optical center as the image intensity falls radially from the optical center making them appear darker at the edges affecting the resultant mosaic image. In literature [4, 5, 6], methods to remove the effects of vignetting from the multiple images acquired from a microscope has been presented. A general purpose and non-parametric method is presented in literature [4] to estimate the illumination field from the background while obtaining images by moving microscope holder. However, the method is not suitable for specimen with very small background in the image. A non-parametric, multi-image based correction method and acquisition scheme for correcting the effects of vignetting and photo-bleaching in fluorescence microscopy has been implemented in [5]. The algorithm learns the correction function by automatically moving the microscope stage at regular intervals and by measuring the changes in intensity. However the learning has to be performed prior to start of image acquisition. In [6], authors implemented a general purpose approach to characterize vignetting and removing its effect from acquired images that can suitably work on-line and does not require any prior information about the camera and the system. This method is based on estimating the vignetting function by detecting and extracting background regions from a sequence of images that is captured randomly in real-time for reconstructing the dense background. Unlike others, this method does not rely on empty field. With the removal of vignetting effect from multiple images, microscopic enhancement and visualization using mosaicing is also the scope in this field.

Appleton et al. [7] addressed the problem of large artifacts that are seen in assembled virtual slide when the unavoidable errors in browsing and alignment stages are left uncorrected. Two types of alignment errors can occur while mosaics are constructed from large number of images. The first type being the difference between mapping model used for alignment and the actual between image-geometric distortions while the second type of error is in alignment caused by mismatch. A 2D grid graph based method is presented in [8] for ensuring globally consistent image mosaics. Manual control of microscopic stage may introduce major error in combining the images. So, it is required basically to handle this problem.

Wongsawatsuriyha et al. [9] presented a method to obtain microscopic image mosaic using motion estimation and multi-resolution blending in which motion length between previous and current feature frame is obtained from motion estimation using a combination of optical flow and phase correlation technique. However, when images are taken in closed loop form, misalignment accumulates and the method is yet to be applied to increase the mosaicing speed for accommodating a video frame rate of 30Hz. Accurate and high speed video mosaic of microscopic images are even required to tackle.

Feature based methods for obtaining mosaic of microscopic images are presented in literatures [10, 11, 12, 13, 14, 15]. Harris corner detection method is used in [10, 11] for detecting and identifying the features from images followed by geometric and radiometric corrections for alignment of images and compensation of intensity differences respectively. Automatic mosaicing of pathological images using Lowe’s Scale Invariant Feature Transform (SIFT) is presented [12] which uses a SIFT characteristic examination algorithm that increases matching precision for automatic feature selection resulting in mosaics. Results are highly accurate even acquired images have small overlapping area. Feature based registration are more suitable for speeding up the system so may be the choice of selection.

Speeded Up Robust Features (SURF) [13] are used for the purpose of mosaicing with application to microscopy images of blood cells. Detection of features is performed by using Hessian matrix and box filters while interest points are located by applying non-maximum suppression and filter up scaling to implement scale space. Matching effect and speed consideration is made during matching of interest points by the Euclidean distance of two Eigen vectors as a measure of similarity. Image fusion is then used to achieve smooth connection between images. Selection of similarity measure and image stitching method plays major role in behavior of the system.

A SURF based mosaicing technique [14] is also implemented with the images from microscope system which has Automatically Controlled Object Stage and Image Capturing Unit. A new method to separate descriptor windows is implemented to increase the speed. RANdom SAmple Consensus (RANSAC) method is used for removing mismatches followed by global normalization of color and light densities prior to blending. This is followed by applying a weighted average method for stitching boundaries in order to blend and create smooth image. Another SURF based method for obtaining mosaic of microscopic images is presented in [15] targeting the limitations and problems occurring in diagnosis of prostate cancer with normal images having small field-of-view (FOV). Detection of features and their description is achieved by using SURF, followed by obtaining coarse matching points using a combination of Bray-Curtis distance and k-d tree algorithm. Fine matching is achieved by RANSAC and final mosaic is obtained by image fusion using fade in-out algorithm. The result is a mosaic with accuracy in feature extraction for slices of microscopic prostate cancer images providing good assistance for diagnosis of disease. RANSAC are direct registration method which lead complex nature. Complexity is needed to be reduced.

Here, an off-line and automatic method for mosaicing of microscopic images for speeding up the system, reducing complexity and for getting accuracy in processing is presented in this work. The microscopist needs to record the video of the slide of whose mosaic is to be obtained. The resulting mosaic image is obtained from a recorded video of a steel bar sample having an artificial crack. The video is recorded by manual movement of microscope stage in negative X- direction (left to right motion of sample) to scan crack on it.

Most of the work presented until now is based on the stitching of multiple images, here stitching of microscopic video frames is considered. Proposed microscopic mosaicing (called µ-mosaicing) is based on Normalized Cross Correlation (NCC) features along the overlapped portions between two consecutive frames of video to speed up the system. Manual motion of microscopic stage is considered instead of calibrated motions. Video with manual motions are having vertical as well as horizontal motions (slanted motions). Manual motion cannot be error and noise free. So, specifically manual motion is considered in this work. Kantilal et al. [16] used Image In-painting to obtain a mosaic image of background from a video sequence by removing dynamic objects.

Yair Poleg and Shmuel Peleg [17] used image in-painting technique in their work for stitching of independent (non-overlapped) images along seam line. They presented a process to align and mosaic non-overlapping images by extrapolating images expecting that extrapolation will bridge the gap between images while alignment is done by recovering their relative positions followed by in-painting the gaps between images to obtain seamless mosaic image. Here, image in-painting is used for stitching of overlapped images.

1.2 Mosaicing of Thermal Images

Wang et al. [18] presented a method for stitching medical infrared images using grid based image registration. Using registration algorithm, a point in the overlap region is selected such that it is not close from the edge of second image with its distance from edge not more than half of the height of grid obtaining the RGB values of the images with this point as center. The best registration point is determined when the quadratic sum of difference of corresponding RGB values in two images so computed is minimum. To avoid blurring and getting gradual transition in the stitched region for obtaining seamless image, a fade-in and fade-out fusion method is used.

A feature based method using Harris method for detection of corner points is implemented in [19] to obtain a single picture by fusing a series of images shot from a thermal camera. The algorithm has four steps as 1) feature point detection by Harris method, 2) feature point matching, 3) determination and creation of transformation model for fusing images and 4) blending the fused image by averaging. However the algorithm is semiautomatic and cannot fuse images if a set of images is given as input. Methods [18, 19] are based on feature based registration and it is important for speeding up the system. Automatic and blur free system design is the aim behind this work.

In our study, it is found that very little work has been done and published on mosaicing of thermal images. A vertical scanning system to create a vertical mosaic image for thermal scan of human body called Thermo-Mosaicing is proposed in this work. It can be used for recording of temperature variations along whole body of human being. Scanning video is used for the creation of mosaic image. Overlapped area is identified by using NCC features and all the frames of video are stitched using image In-painting along overlapped region. Automatic, fast and accurate mosaic nature is observed from results of proposed algorithm.

2. METHODOLOGY

Separate and specific methodologies for µ-Mosaicing and Thermo-Mosaicing are considered based on circular/linear stitching and image in-painting. These methods are discussed in following sub-sections.

2.1 µ-Mosaicing

A novel approach of µ-Mosaicing is proposed to combine the microscopic images. This method is an overlapped method for mosaicing of images from a microscopic video sequence that has the natural circular field of view images as seen from the eyepieces as shown in Fig. 1 below. Here, the direction of motion of microscopic slide is considered particularly in slanted direction involving horizontal and vertical motion simultaneously.

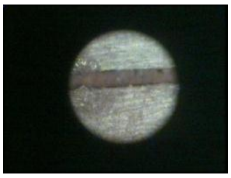


Fig. 1: Image with Circular Viewing Area of Microscope obtained by Camera

Since mosaic is prepared from frames of a video sequence, its accuracy will be achieved mainly in the registration of consecutive frames. Also redundant data may be available in consecutive frames if the microscope stage is not moved properly while acquiring the video. To eliminate this, Key Frame Selection process is employed. However, the selection of key frames should be such that the region of overlap should contain enough information to maintain the continuity of the mosaic. In the proposed method, selection of key frame is achieved by using image matching algorithm.

The steps involved in the proposed algorithm of µ-Mosaicing are as follows.

1. Convert the microscopic video into frames.
2. Detect the radius and centre point co-ordinates of the circular microscopic view in the rectangular frame of video.
3. Get the rectangular strip of image from the circular view in the starting frame (initial key frame) or initial mosaic along front edge.
4. Match this strip in the succeeding frames. The frame that satisfies the maximum matched registration criteria is the key frame (2nd key frame).
5. Stitch initial frame or initial mosaic and 2nd key frame.
6. Repeat the steps 3 to 5 by assigning new mosaic as initial mosaic to obtain the mosaic as shown in Fig. 2(a) below followed by cropping the image as shown in Fig. 2(b).

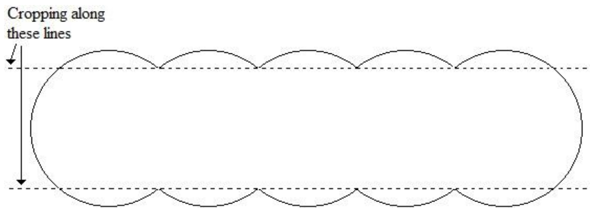
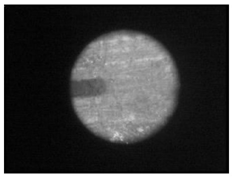


Fig. 2(a): Wavy Mosaic formed after scanning One Complete Line of Specimen under Microscope

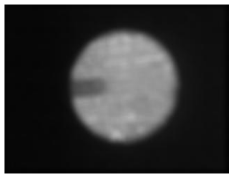
Fig. 2(b): Final Mosaic obtained after Cropping

2.1.1 Detection of Circle, Radius and Centre in Image

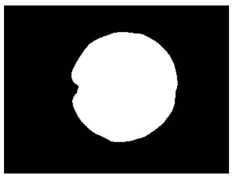
A shown in the Fig. 1 above, all of the information is contained in the circular part of the frame. Hence prior to processing for the image registration, it is necessary to detect the boundary of the circle, its radius and its centre co-ordinates to identify the maximum information area. This is achieved by 1) converting the frame into grayscale, 2) filtering and binarization 3) Circular Hough Transform on binary image. Since this method detects a family of circles, the black pixels in the view present near the edges of circle along objects may result in inaccuracy if filtering is not applied. Filtering the grayscale image by an average filter of size 10 x 10 before binarization is responsible for exact circle detection.



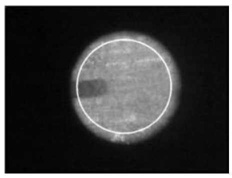
(a)



(b)



(c)

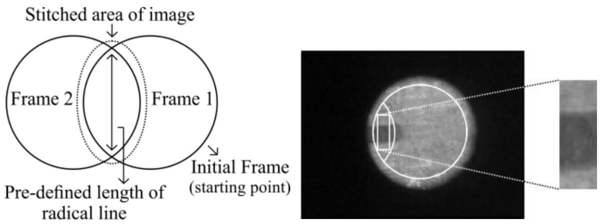


(d)

Fig. 3: Circle Detection – (a) Input Image in Grayscale, (b) Image after Filtering, (c) Binary Image (d) visualization of Detected Circle

2.1.2 Obtaining a Rectangular Strip from Initial Key Frame

Since proposed key frame selection method is based on image matching, rectangular strip from the probable overlapping part of the key frame and current frame is extracted. The area of probable overlap is estimated from the location of the circular view in the next key frame so as to have a pre-fixed length of radical line. Currently the length of radical line is selected by deciding the height of mosaic image.



(a) (b) (c)

Fig. 4: (a) Key Frame Selection Process, (b) Estimation of Overlap Area to obtain Rectangular Strip Image, (c) Rectangular Strip cropped from Overlapping Area (Enlarged View)

The elliptical overlapping area formed, as shown in Fig. 4 above, is estimated in terms of the distance between the centers of the circles and radical line distance. The distance of the radical line from the centre of the circle in, say R_D is estimated. Based on these parameters, rectangular image of maximum size that fits within this area is estimated and used for obtaining next key frame which is called as a template image.

2.1.3 Obtaining the Next Key Frame

The template image obtained in the previous step is used for key frame selection based on strip matching algorithm. Here, area based image matching technique and essentially the NCC method is used for matching purpose. Use of NCC helps to determine the location of maximum match point that will help in performing geometrical transformations such as shifting and rotation on the image before stitching. NCC method requires two images 1) the template image that is to be matched 2) the image of size greater than the template image in which the template is to be located. NCC provides correlation coefficients between -1.0 to 1.0 where the maximum value is obtained at the point of match. From this point, the location of the template in the key frame can be identified. Search for key frame is made by performing NCC of the template and the next frame continuously until a frame is obtained in which the centre of the match strip falls within the overlapping area. This is identified by finding the centre of the matched strip at distance R_D. This next key frame is required to be stitched to the starting key frame.

2.1.4 Stitching of Frames to Form Mosaic

Initial frame and the next key frame obtained from key frame selection algorithm are modified to remove the blurred edges of circular part of frame. It is also necessary to remove vignetting effect along the edges of microscopic circular view.

(a) (b)

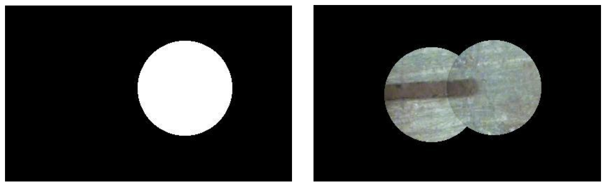
Fig.5: (a) First Key Frame 1 – Start of Microscopic Slide, (b) Next Key Frame (say Frame 2) obtained by Key Frame Selection Process

To stitch these two images together as shown in Fig. 5(a) and Fig. 5(b), both frames need to be shifted such that the coordinates of the centre point of template in its source image will be same as that in the next key frame so that the overlap of the two frames will give us an exact mosaic. The size of the two images must be same after shifting for stitching purpose. Morphological shift and rotate are used to create image as shown in Fig. 6(a) and Fig. 6(b) respectively.

(a) (b)

Fig. 6: (a) Shifted Frame 1, (b) Shifted Frame 2

3-point Mask Blending Algorithm [20] is used to combine two images. The two shifted frames and a mask are then input to the 3-point Mask Blending Algorithm that performs stitching of the two images but may visualize seam line along boundary. The mask is a binary image of the same size as that of two frames which is created such that it has white pixels in the informative area coinciding with the microscopic view in Frame 1. Mask is shown in Fig. 7(a).



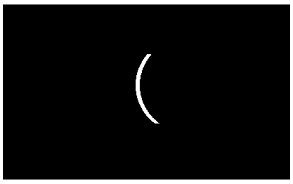
(a) (b)

Fig. 7: (a) Binary Mask Image, (b) Output of 3-point Mask Blending of Frame 1 and Frame 2

Fig. 7(b) is the result obtained after combining the images shown in Fig. 6(a), 6(b) and 7(a) as an input to 3-point Mask Blending Algorithm.

Steps 3 to 5 of the µ-Mosaicing algorithm are repeated for the complete video sequence to obtain all the key frames and to stitch them one by one together as shown in Fig. 14. However, due to intensity differences caused by reflection from the surface of the metal sample under microscope, seams are visible in the overlapping region. These seams are removed by using an Image In-painting algorithm proposed by Criminisi et al. [21] since it can visualize pleasing transitions along the overlapping region. Image in-painting algorithm removes the visible seams by modifying the pixel values depending on the neighboring pixels of the in-painted region.

In-painting the blended images to remove the seam line require a mask image as shown in Fig. 8(a) overlaid on the blended image before in-painting. The images can be in-painted just after stitching a new frame to the mosaic or the whole mosaic can be in-painted at once after stitching process is completed. In-painting the complete mosaic is depicted in Fig. 14 through Fig. 17. The image is then rotated to obtain a horizontal wavy mosaic, shown in Fig. 18 that is similar to that depicted in Fig. 2(a). It is then cropped to a height equal to radical line as shown in Fig. 19 and as depicted in Fig. 2(b).



(a)

(b) **(c)**

Fig. 8: (a) Binary Mask Image for In-painting, (b) Mask overlaid on Stitched Frame 1 and Frame 2, (c) In-painted Image

2.2 Thermo-Mosaicing

Overlapped mosaicing of thermal images called Thermo-Mosaicing from a video sequence for application in medical field is also proposed. The human body scan video [22] with the help of a thermal camera mounted on a motorized vertical sliding mechanism with the motion from top to ground direction is considered for vertical mosaicing. With same algorithm, motion in the opposite direction can also be handled. The sliding mechanism should operate at an optimum speed to accommodate the refresh rate of the camera. If it is slow, frames having redundant data may be present increasing the overall processing time and small changes in body temperatures may take place affecting further observations and analysis because of time delay. If it is too fast, blurriness may occur in the frames of the video.

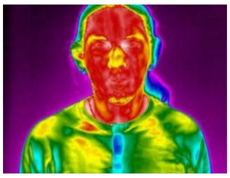


Fig. 9: Image acquired using Thermal Camera (Frame 1)

As proposed in µ-Mosaicing process, key frame selection using image matching is also employed in mosaicing of thermal images. The steps involved in the proposed Thermo-Mosaicing algorithm are:

1. Convert the thermal video into frames.
2. Get the horizontal rectangular strip image from bottom of image. This strip will be used for image matching. And a frame is considered as initial key frame or initial mosaic.
3. Match the stripped image in the succeeding frames. The frame that satisfies maximum matching registration criteria is the key frame.
4. Stitch the key frame obtained in step 3 to the initial key frame (or initial mosaic) in step 2 to create new mosaic.
5. Repeat steps 2 to 4 by assigning new mosaic as initial mosaic to obtain the mosaic as shown in Fig. 20(a).

2.2.1 Obtaining Rectangular Strip Image and Next Key Frame

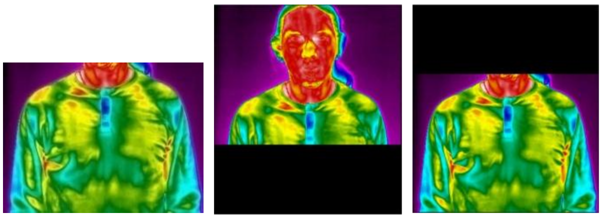
Since key frame selection method used is based on image matching using NCC, a template image is required which is a horizontal rectangular strip got from the starting frame of the video (from Frame 1). The height of template is taken equal to approximately one eight of the frame height to speed up the NCC process and to obtain accurate key frames.

Fig. 10: Template Image

As with µ-Mosaicing method, NCC based matching technique is used for matching the template in succeeding frames of the video. NCC provides the correlation coefficients between -1.0 to 1.0 and provides maximum value at maximum match points. From the match points, the distance, say R_T, of the strip location in the image from the top end of the frame is obtained for frame alignment. Currently, key frame is selected as the one in which the distance R_T reaches approximately half of the frame height. This will increase the number of frames to be stitched, increasing the processing time, but will provide mosaics that retain the changes in the colors which often found due to background temperature changes during motion of thermal camera. Intensity correction is performed to match the intensities between two consecutive key frames so that they can be combined with minimum efforts and with proposed steps.

2.2.2 Stitching of Frames to Form the Mosaic

Fig. 11(a) show the key frame obtained by matching the template with the consecutive frames of video.

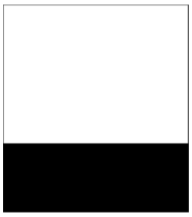


(a) **(b)** **(c)**

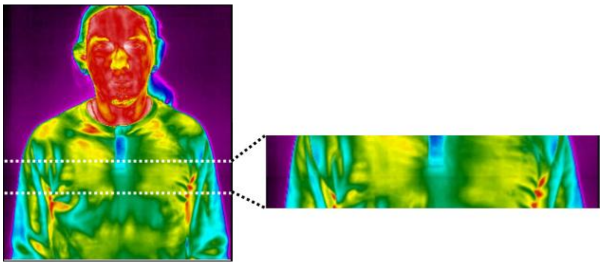
Fig. 11: (a) First Key Frame (say Frame 2), (b) and (c) Frame 1 and 2 respectively after Shifting

The two key frames to be stitched needs to be aligned so that the location of the match points in both the images must be same so that they can be overlapped to form a mosaic. Two key frames are aligned using morphological shifting as shown in Fig. 11(b) and Fig. 11(c). The two shifted frames must be of the same size for combining them.

A 3-point Mask Blending Algorithm, as used in µ-Mosaicing, is used for combining the frames to obtain the mosaic. The mask is a binary image of same size as the two frames to be stitched. It has white pixels in the area coinciding with the thermal image in Frame 1. Resultant image of 3-point Mask Blending Algorithm is shown in Fig. 12(b) which even visualizes seam line (Fig. 12(c)) that is further required to be removed.



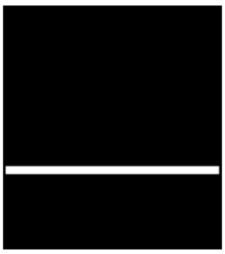
(a)



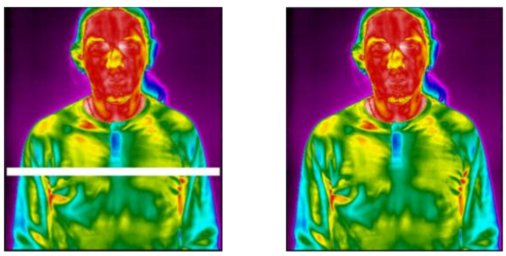
(b) (c)

Fig. 12: (a) Mask used for Stitching Frames 1 and 2, (b)Result after combining Frames 1 and 2 (Combined Image), (c) Visible Seam Line

Steps 2 to 4 of the Thermo-Mosaicing algorithm mentioned above are repeated for the complete video sequence to obtain all the key frames and stitch them together as shown in Fig. 20(a). Image In-painting as used in µ-Mosaicing, is used for removal of visible seam. In-painting for seam removal requires a mask image shown in Fig. 13(a) overlaid on the mosaic as shown in fig. 13(b).



(a)



(b) (c)

Fig. 13: (a) Mask required for Image In-painting, (b) Mask on Combined Image, (c) In-painted Image

In-painting of mosaic is performed as soon as frames are combined together to remove seam line (Fig. 13(c)) or it can be done after all the key frames are stitched together. The mosaic after stitching all key frames of video, mask for its in-painting, mask overlaid on the mosaic and the seamless mosaic is shown in Fig. 20(d).

3. RESULTS

The µ-Mosaic obtained from the proposed method is shown in Fig. 14. The in-painted mosaic in Fig. 17 and the cropped mosaic in Fig. 19 are the final resultant images. Since this method does not employ any intensity correction measures prior to stitching, seams are visible in the stitched image. However, those have been removed with the help of image in-painting. The Thermo-mosaic obtained from proposed method is shown in Fig. 20(a). Image In-painting can be done after all key frames are combined together during Thermo-Mosaicing Algorithm. The mask overlaid on the combined mosaic and the seamless mosaic is shown in Fig. 20(c) and Fig. 20(d) respectively.

The codes for µ-mosaicing and Thermo-mosaicing is written and tested in MATLAB on a PC with Intel Core-i7 processor accompanied by 12GB RAM. The total time for µ-mosaicing, as measured from MATLAB with all normal OS services running, required to obtain the results from a pool of 758 frames (each of 320×240 pixels in size) as shown in Fig. 19 is approximately 12.72 minutes. While the total time for Thermo-mosaicing, as measured from MATLAB with all normal OS services running, required for obtaining the results from a pool of 634 frames (each of 480×360 pixels in size) as shown in Fig. 20(d) is approximately 21.92 minutes.

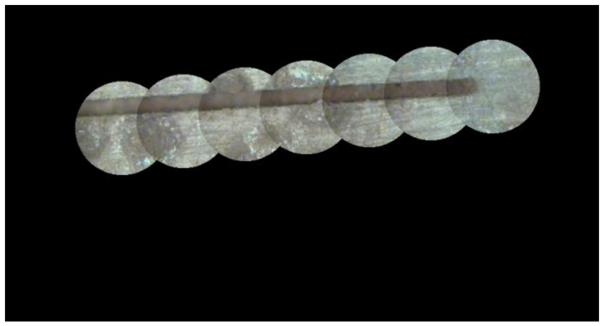


Fig. 14: Result of Stitching 7 Frames from the given Input Frames of Videos

Fig. 15: Binary Mask for Simultaneously In-painting 7 Stitched frames

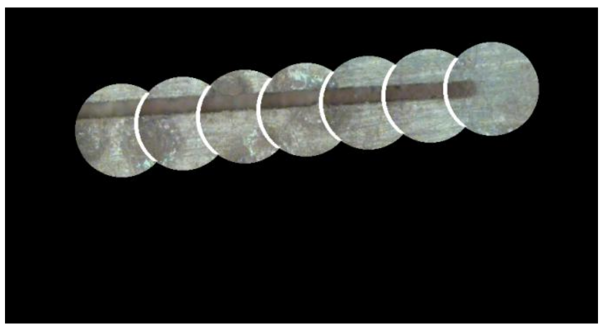


Fig. 16: Mask in Fig. 15 overlaid on Image in Fig. 14

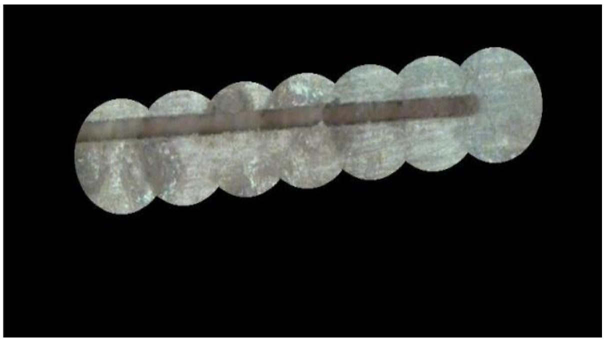


Fig. 17: Result of Image In-painting

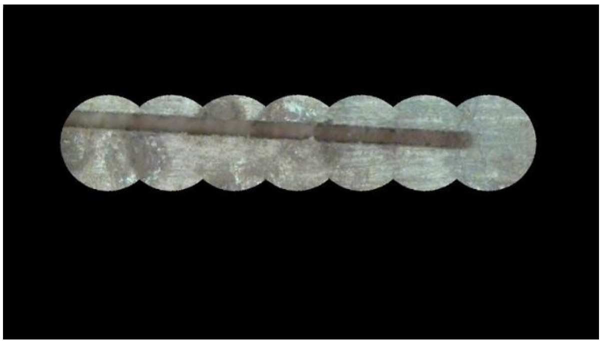
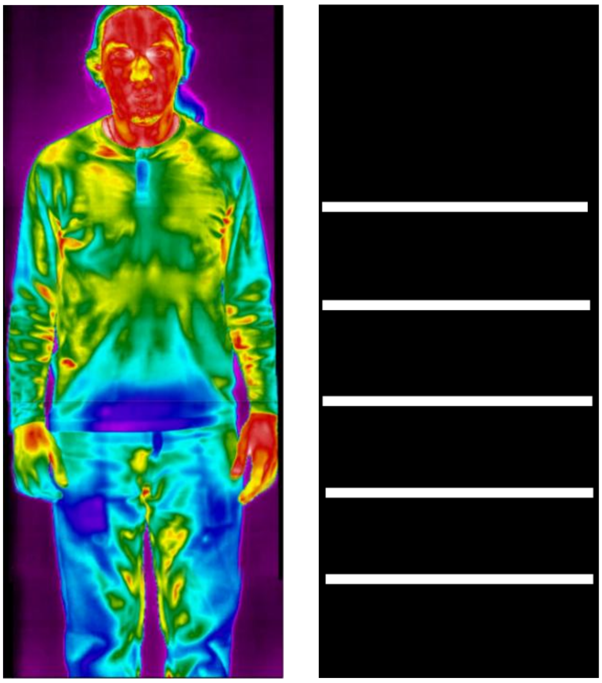
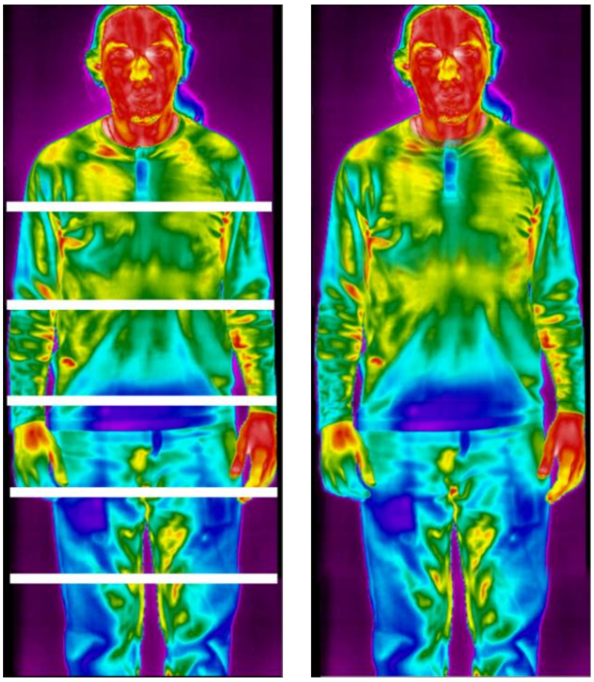


Fig. 18: In-painted Mosaic rotated to make it horizontal

Fig. 19: Cropped Image with Height Equal to Length of Radical Line



(a) **(b)**



(c) **(d)**

Fig. 20: (a) Mosaic obtained after stitching all Key Frames, (b) Mask for In-painting the Mosaic, (c) In-painting Mask overlaid on the Mosaic, (d) Seamless Mosaic after In-painting

4. CONCLUSION

A new approach to mosaic microscopic images called µ-Mosaicing is proposed here. From the experimentation, visually pleasing results are obtained. However, µ-Mosaicing does not perform any intensity corrections on the frames of video sequence and has been used for offline mosaicing involving a pre-recorded video. Future scope includes extending the current implementation to form an automatic system consisting of manually/randomly controlled microscopic stage to acquire the whole microscopic specimen from any directional motion to create final full mosaic image. Linearity, clarity, accuracy reflects from the mosaic results from proposed µ-Mosaicing algorithm. A new approach for mosaicing of thermal images called Thermo-Mosaicing is also proposed in this work. Vertical Stitching using Key Frame Selection, 3-point Mask Blending Algorithm and Image In-Painting is performed on thermal video taken from human body. Blurring effect and intensity variation while capturing is handled to create noise free and sharp mosaic. Observing the mosaic results from proposed Thermo-Mosaicing algorithm reflects the clarity and its accuracy.

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