

Effectiveness of Initial Segmentation Technique for Mitral Valve in Off-Line Cardiac Ultrasound Images

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Abstract

The current MATLAB-based mitral valve segmentation method is manual, allowing users to define the region of interest and adjust the segmenting angle, but it suffers from being operator-dependent, leading to inconsistent and low reproducibility results. Additionally, edge-based segmentation methods are prone to over and under-segmentation issues. This project addresses these drawbacks by implementing an automatic clustering technique for mitral valve segmentation. Clustering partitions pixels based on feature similarity discover inherent data structures without requiring prior training and avoid the complexity and slow convergence associated with spatially dependent methods like region growth, potentially improving segmentation accuracy and efficiency. This project evaluates the effectiveness of an initial segmentation technique for the mitral valve in random cardiac ultrasound images, focusing on realigning potential risks, analysing, and understanding valve movement through clustering-based segmentation methods. The study preprocesses images using Canny-Edge Detection and applies clustering techniques for segmentation, followed by developing a GUI prototype using MATLAB for user performance testing. Results demonstrate mitral valve movement over four cardiac cycles in healthy and unhealthy hearts, measuring diameters during the opening and closing phases. Healthy hearts showed a minimum opening diameter of 0.32 cm and closing diameter of 0.30 cm, while unhealthy hearts had a minimum opening diameter of 0.25 cm and closing diameter of 0.28 cm. This project enhances the understanding of image processing in cardiac health assessment, particularly non-invasive mitral valve evaluation using segmentation techniques.

1. Introduction

Medical image processing is a specialized field that focuses on developing reliable techniques to enhance, analyze, and interpret medical images from various modalities, such as X-rays, CT scans, MRI, ultrasound, and PET (Bushong, S. C., 2020). Key steps in image processing include preprocessing, segmentation, feature extraction, and enhancement (Jan, J., 2019). Specifically, image segmentation identifies and maps regions of interest within medical images, employing methods like thresholding, edge-based, region-based, and energy-based techniques (Abdulateef, S. et al., 2021). These methods are crucial for accurately identifying anatomical structures, tumours, lesions, and other clinical features, essential for accurate analysis and diagnosis. The main goal is to improve image quality, extract clinically relevant information, and aid in diagnosis and treatment

planning. The heart, a muscular organ in the chest, plays a vital role in blood circulation, supplying oxygen and nutrients while removing waste (Hall, J. E., 2016). It comprises four chambers and four primary valves, with the mitral valve preventing backward blood flow during ventricular contraction. Detecting the mitral valve's shape and location is crucial for early diagnosis and identifying blood flow abnormalities (Schmitz, F. et al., 2022).

2. Methodology

Fig. 1 presents a detailed flowchart outlining the development of a graphical user interface (GUI) for segmenting the mitral valve in ultrasound images using MATLAB software and a clustering technique.

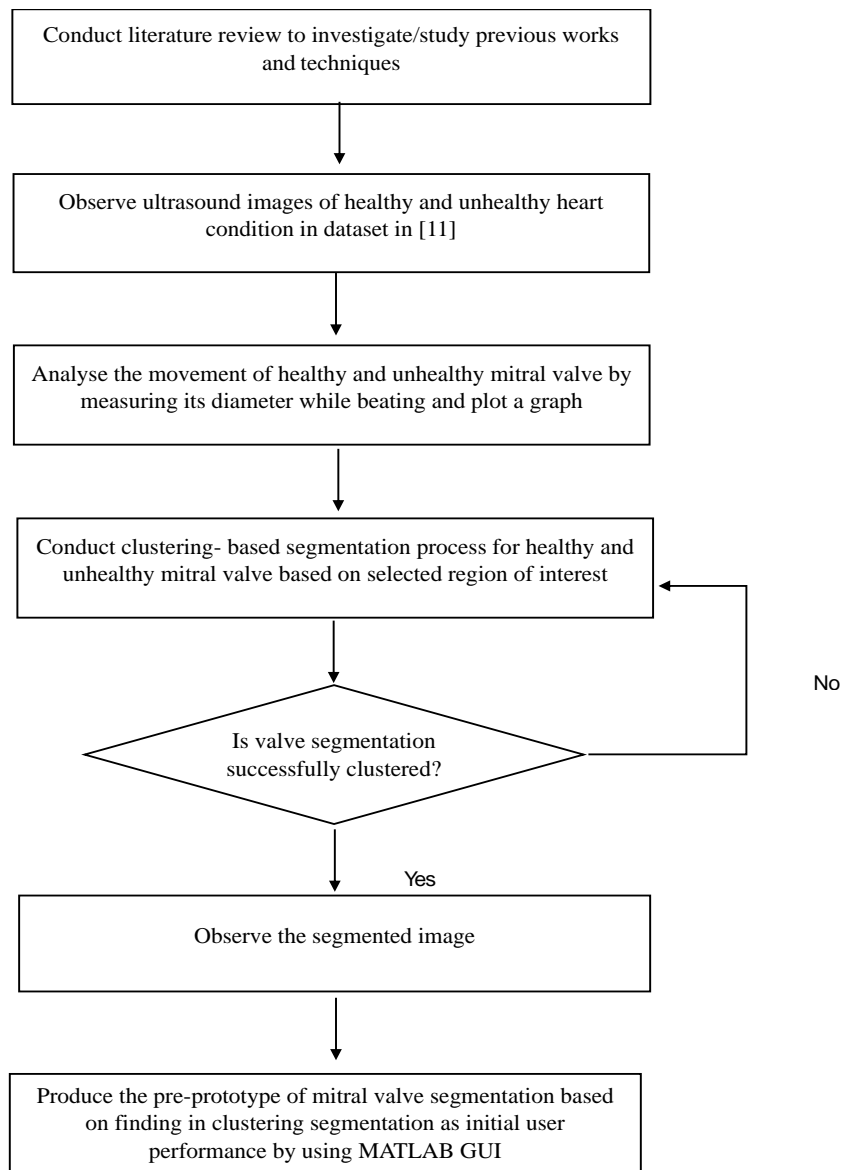


Fig. 1 Flowchart of the system

The initial step in the process involves a comprehensive literature review, which includes examining previous research papers, articles, and technical reports. This review explores existing methodologies, techniques, and advancements in mitral valve segmentation. By gathering insights from prior studies, the project establishes a foundation of knowledge and identifies potential improvements that can be applied to the current segmentation approach. Following the literature review, the project analyses ultrasound images of healthy and unhealthy mitral valves from a designated dataset. This analysis includes measuring the diameter of the mitral valve throughout the cardiac cycle and plotting these measurements using MATLAB. The resulting graphs provide a visual representation of the valve's movement and performance, highlighting differences between healthy and unhealthy conditions. This step is crucial for understanding the dynamic behavior of the mitral valve

and establishing parameters for the subsequent segmentation process. The next phase involves implementing the segmentation process using K-Means Clustering, a clustering-based technique focusing on selected regions of interest within the ultrasound images. K-Means Clustering is employed to differentiate between healthy and unhealthy mitral valve conditions by partitioning the image pixels based on their feature similarity. The final stage of the project is the development of a pre-prototype of the mitral valve segmentation system. This prototype is built using MATLAB GUI tools and integrates the findings from the clustering segmentation to provide an initial performance evaluation for users. The GUI facilitates interaction with the segmentation system, allowing for further refinement and testing based on user feedback.

3. Conversion of pixel to centimeter

In this project, the measurement of the diameter for both the left and right mitral valves in healthy and unhealthy conditions has initially been conducted in pixel units. Since these measurements are taken directly from images of the mitral valve, the pixel values need to be converted to standard measurement units to provide meaningful and comparable results. The conversion process ensures that the diameters are reported in units such as millimeters or centimeters, which are more suitable for clinical evaluation and comparison. To perform this conversion, it is necessary to first calculate the conversion factor that translates pixel measurements into standard units. This involves determining the pixel-to-unit ratio, which can be obtained by using known reference objects of a standard size in the images or by applying calibration techniques. The formula used for this conversion will be based on these reference values, allowing accurate translation from pixels to physical measurements. This step is crucial for ensuring that the results are both precise and useful for further analysis. Once the conversion factor has been established, all diameter measurements can be recalculated from pixel units to the desired standard measurement units. With the conversion factor applied, each pixel-based diameter measurement is adjusted to reflect its true size in physical terms. This ensures that the diameter measurements of the mitral valves are accurate and consistent, facilitating a reliable assessment of valve conditions across different images and subjects.

Image pixels for normal mitral valves image = 582 x 582 pixels (Ouyang, D., n.d.)

582 pixels = 12.52 cm (Dia Foto Film Scannen, n.d.)

$$\text{Diameter of normal mitral valve} = \frac{582}{12.52} (1 \text{ cm})$$

$$1 \text{ cm} = 46.49 \text{ pixel}$$

Image pixels for abnormal mitral valves image = 112 x 112 pixels (Ouyang, D., n.d.)

112 pixels = 2.41 cm (Dia Foto Film Scannen, n.d.)

$$\text{Diameter of normal mitral valve} = \frac{112}{2.41} (1 \text{ cm})$$

$$1 \text{ cm} = 46.47 \text{ pixel}$$

4. Results and discussion

The project's main goal is to perform edge detection on heart echocardiography images using the Canny method and segment the mitral valve region using K-means clustering by using MATLAB software

4.1 Measurement of healthy and unhealthy mitral valve

These are measurements of the healthy and unhealthy mitral valve diameters at two points, A and B. Point A is from the middle of the left mitral valve to the middle of the right mitral valve, and Point B is from the end of the left mitral valve to the end of the right mitral valve. Line graphs created in MATLAB show the mitral valve's movement in healthy and unhealthy hearts. Fig. 2 and Fig. 3 illustrate points A and B for both heart conditions.

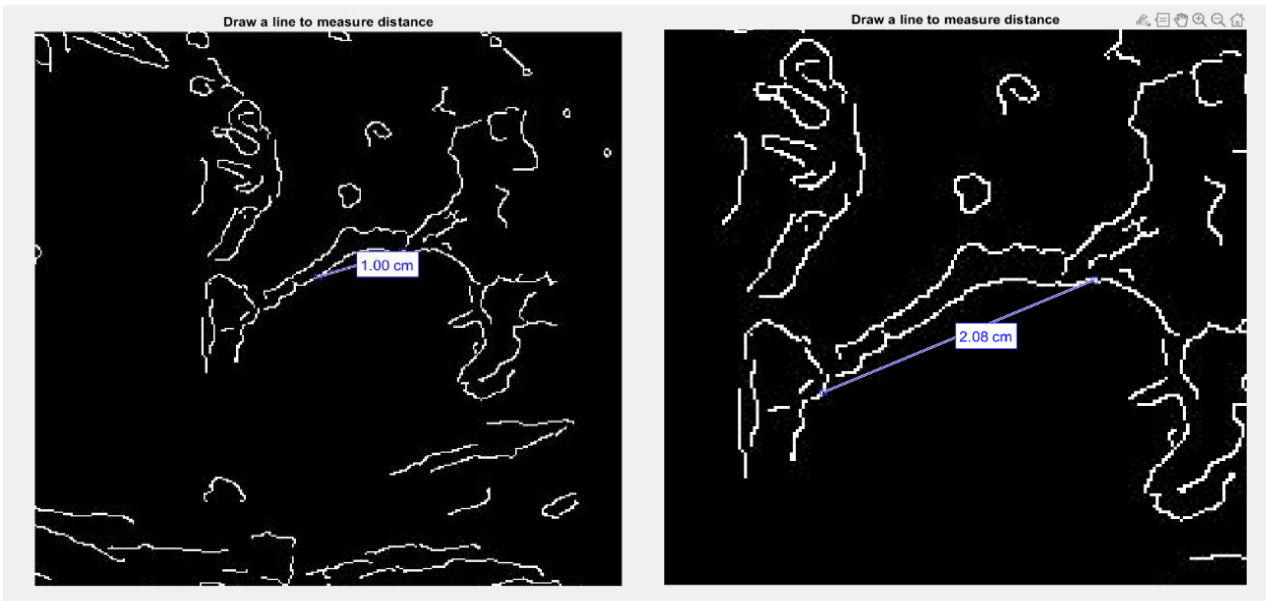


Fig. 2 Point A and Point B for healthy heart respectively

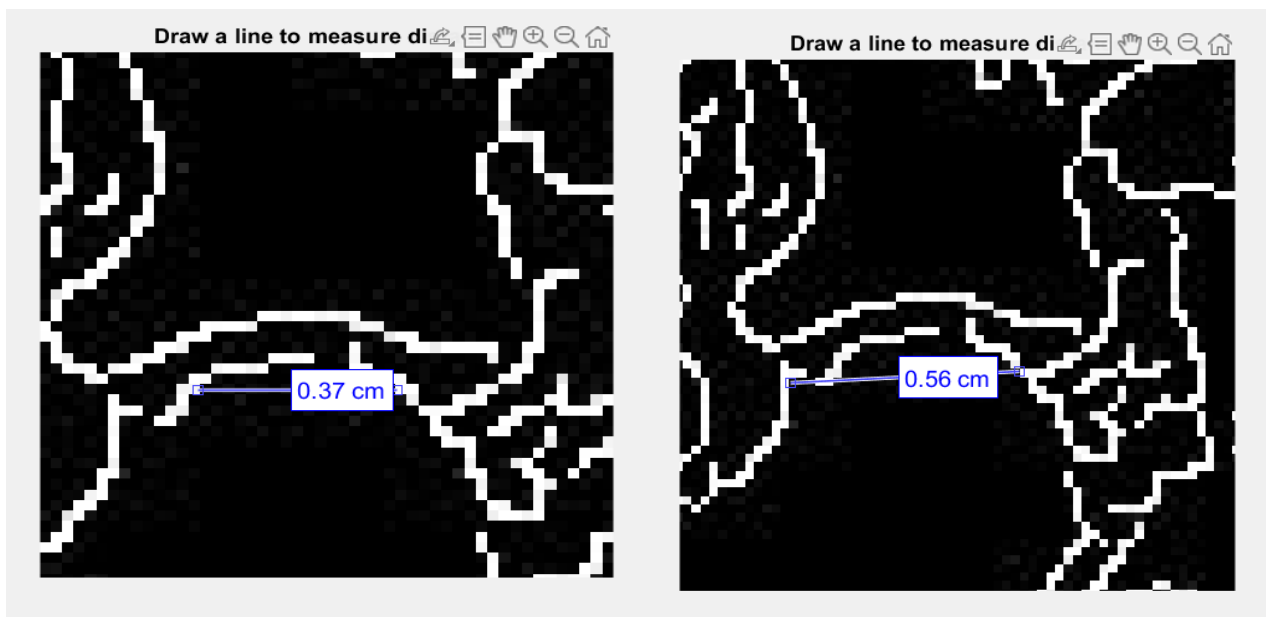


Fig. 3 Point A and Point B for unhealthy heart respectively

In this project, we measure the diameters of the mitral valve at two distinct points, A and B, to analyze its behavior in both healthy and unhealthy hearts. Point A measures the diameter from the middle of the left mitral valve to the middle of the right mitral valve, providing insight into the central span of the valve. Point B measures the diameter from the end of the left mitral valve to the end of the right mitral valve, capturing the full extent of the valve's opening and closing. These measurements are critical for assessing how the mitral valve functions and changes during the cardiac cycle. To visualize these measurements and understand the mitral valve's movement, line graphs are generated using MATLAB. These graphs plot the diameter measurements over time, allowing us to observe how the valve's dimensions fluctuate in healthy and unhealthy conditions. By comparing these graphs, we can identify differences in valve function and detect any abnormalities or deviations in the mitral valve's behavior that may indicate pathological conditions. Figures 2 and 3 in the study illustrate the positions of points A and B for both healthy and unhealthy hearts. These figures provide a visual reference for how the measurements are taken and represented. They help to contextualize the data presented in the line graphs by showing the specific locations on the mitral valve where measurements are recorded. This visual representation aids in interpreting the results and understanding the dynamic changes in the mitral valve's diameter across different cardiac states.

4.2 Result of healthy mitral valve diameter in images

31 figures of healthy mitral valves selected to represent one cardiac cycle have been analyzed and measured in diameter. The diameter of the normal mitral valve is measured in centimeters using MATLAB software. Table 1 shows the sample of diameter measured, which is only up to Fig. 4.

Table 1 Diameter of normal mitral valve for point A and point B

Figure	Time of image sequence (ms)	Diameter of normal mitral valve (cm)	
		Point A	Point B
1	30	0.63	1.92
2	60	0.64	1.89
3	90	0.65	2.00
4	120	0.58	2.02
5	150	0.71	2.04
6	180	0.79	2.04
7	210	0.70	2.06
8	240	0.60	2.08
9	270	0.55	2.10
10	300	0.63	2.23

The measurements obtained from the mitral valve diameter at points A and B reveal distinct patterns in the valve's behavior. At Point A, the diameter demonstrates a trend pattern characterized by an initial decrease, an increase, and a subsequent decrease. This fluctuating pattern may reflect the dynamic nature of the valve's opening and closing during the cardiac cycle, highlighting variations in the valve's central span as the heart beats. In contrast, the diameter at Point B exhibits a different trend: an initial increase is followed by a decrease and then a subsequent increase. This pattern indicates changes in the extent of the valve's opening and closing, possibly due to varying pressures and forces during the cardiac cycle. The time sequence of the images used for these measurements ranges from 30 milliseconds for the initial frame to 930 milliseconds for the final frame. This time variation allows for a detailed analysis of the mitral valve's movement over a substantial period, providing insights into how the valve behaves over time. The extended time sequence helps capture the complete cycle of the valve's function, from its opening to closing phases. It offers a comprehensive view of its dynamic performance under different conditions. To further analyze the mitral valve's movement, a graph was plotted based on the obtained diameter measurements. This graph illustrates the changes in the valve's diameter at points A and B over time, providing a visual representation of the valve's behavior throughout the cardiac cycle. By examining the graph, one can assess how the mitral valve's dimensions vary and identify any irregularities or trends indicative of healthy or unhealthy heart conditions. This analytical approach enhances the understanding of the mitral valve's function and supports evaluating its performance in different physiological states.

The graph generated in MATLAB provides a detailed view of the mitral valve's movement by plotting diameter measurements at two distinct points, A and B. At Point B, the graph reveals an increasing pattern, which correlates with the valve opening. As the diameter at this location enlarges, it signifies that the valve is expanding to accommodate blood flow. Conversely, a decreasing pattern at Point B indicates that the valve is closing, with the diameter shrinking as the valve returns to its resting state. This behavior reflects the valve's functional response to the heart's pumping action and provides insights into its operational dynamics. In contrast, the graph for Point A shows an opposite trend. Here, a decreasing pattern corresponds to the valve opening, while an increasing pattern signifies the valve closing. This discrepancy arises from the differing locations of Points A and B. Point A is situated in the middle of the valve, where the diameter measurement reflects a central aspect of the valve's movement. As the valve opens, the middle diameter decreases due to the inward motion of the valve leaflets, and it increases as the leaflets move outward during closure. The variation in measurement trends between Points A and B highlights the influence of their respective positions on the valve's diameter readings. Point A, being centrally located, captures changes in the valve's central span, while Point B, located at the ends, monitors the extent of the valve's opening and closing. This positional difference results in opposite trends for the same valve movements, underscoring the importance of measurement location in interpreting mitral valve function. Understanding these trends helps in accurately assessing the valve's behavior and diagnosing any potential abnormalities based on its dynamic performance.

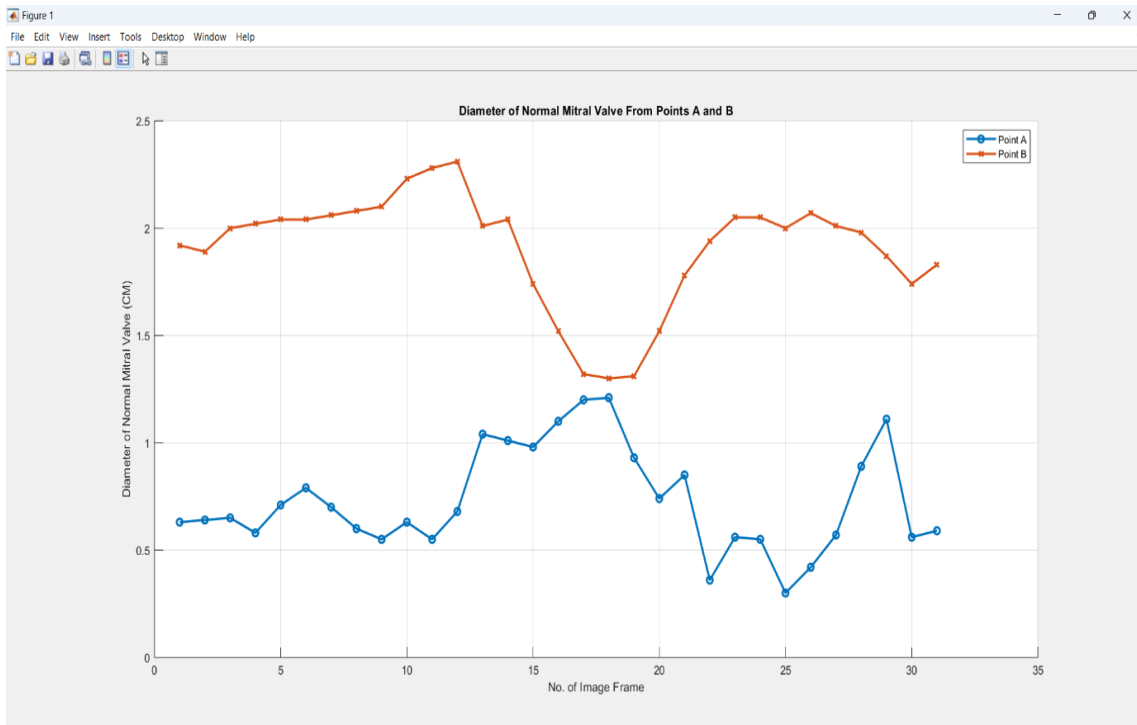


Fig. 4 Point A and Point B for healthy heart respectively

4.3 Result of unhealthy mitral valve diameter in images

60 figures of unhealthy mitral valves selected to represent one cardiac cycle have been analyzed and measured in diameter. The diameter of the normal mitral valve is measured in centimeters using MATLAB software. Table 2 shows the sample of diameter measured, which is only up to Fig. 5.

Table 2 Diameter of abnormal mitral valve for point A and point B

Figure	Time of image sequence (ms)	Diameter of abnormal mitral valve (cm)	
		Point A	Point B
1.	20	0.31	0.61
2.	40	0.33	0.59
3.	60	0.31	0.60
4.	80	0.31	0.58
5.	100	0.29	0.56
6.	120	0.31	0.55
7.	140	0.33	0.55
8.	160	0.35	0.55
9.	180	0.37	0.57
10.	200	0.39	0.55

The analysis of the unhealthy mitral valve, measured in centimeters using MATLAB, reveals distinct characteristics in the diameter measurements at points A and B. At Point A, the diameter measurements do not exhibit significant trends, reflecting the abnormal movement of the valve. In this case, the right mitral valve remains relatively stationary compared to its healthy counterpart, resulting in minimal variations in the diameter. The lack of substantial change indicates that the valve is not performing its normal opening and closing functions, which can indicate pathological conditions affecting valve mobility. Similarly, the measurements also fail to show a clear trend at Point B. The diameter at this location does not exhibit a consistent pattern of increase or decrease, which further suggests that the valve's movement is impaired. This lack of a defined trend indicates the valve's compromised functionality, where normal cyclic changes in diameter are disrupted. The absence of clear trends at both measurement points highlights the severity of the valve's abnormal behavior and its deviation from expected physiological patterns. The image sequence for these measurements ranges from 20 milliseconds for the initial frame to 1200 milliseconds for the final frame, capturing a broad temporal range of the valve's movement. Despite this extended time span, the plotted graph of

the mitral valve diameter does not reveal any meaningful patterns. This lack of clear trends underscores the difficulties in assessing valve function in unhealthy conditions, where the expected cyclic variations in diameter are not observed. The graph serves as a tool for analyzing the abnormal movement of the mitral valve, providing insights into the extent of its dysfunction and guiding further diagnostic and therapeutic interventions.

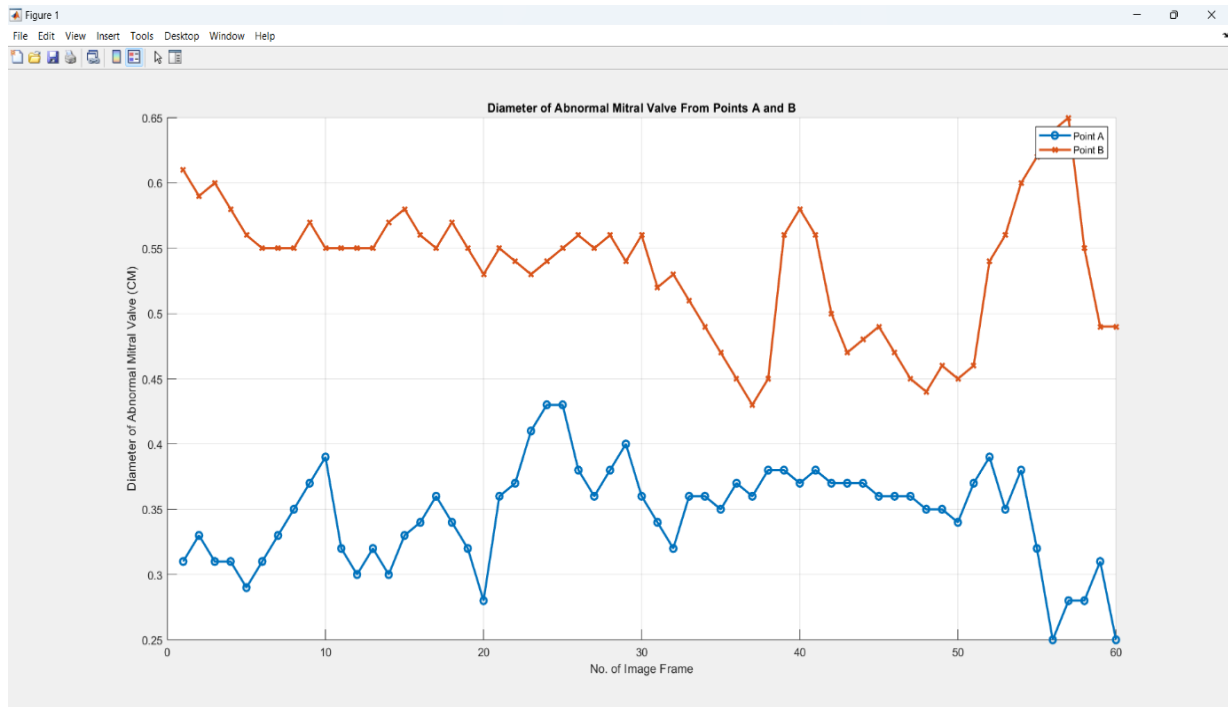


Fig. 5 Point A and Point B for unhealthy heart respectively

The graph generated in MATLAB for abnormal mitral valves illustrates the movement of the valve based on diameter measurements. Due to abnormalities, the observed movement is atypical compared to normal valves. Specifically, in cases where the abnormality causes the right mitral valve to remain largely stationary, the left mitral valve becomes the primary focus of measurement. Consequently, the graph does not display well-defined patterns in healthy valves. However, despite the lack of significant trends, the graph still reveals some movement, with increasing and decreasing diameter trends observable in the data. In the subset of images from frames 50 to 60, the opposite movement trends at points A and B are still evident, albeit in a less pronounced manner. At Point B, the graph shows an increasing trend, indicating that the valve is opening and the diameter is enlarging. Conversely, at Point A, the graph reveals a decreasing trend, signifying that the valve is closing, and the diameter is reducing. These observations align with the expected behavior of a mitral valve, where point B captures the expansion during the opening, and point A captures the contraction during closing. Even though these patterns are less clear due to the valve's abnormal movement, they still reflect the underlying mechanical functions of the valve. Even in abnormal conditions, detecting these trends provides valuable insights into the mitral valve's operational state. Observing the increasing and decreasing trends at points A and B confirms that some level of functional dynamics remains, despite abnormalities. The graph's depiction of these movements, while less distinct than in healthy valves, helps understand the extent of the valve's dysfunction and offers a basis for further analysis and potential intervention strategies.

4.4 Designing GUI

GUI or Graphic User Interface Design can help users use the program easily. The design should be easy to use and efficient so that it can ease the user, especially those who do not have experience using it. Fig. 6 shows the GUI layout.

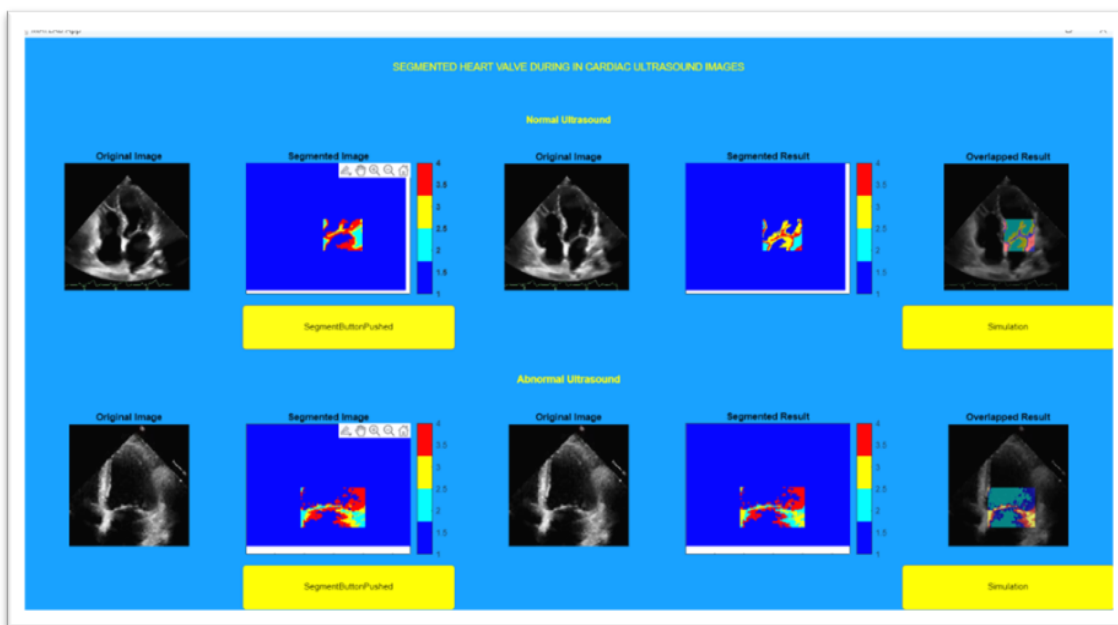


Fig. 6 GUI layout

The step begins when the user clicks the “SegmentButtonPushed” button; a window will pop up, allowing them to select an image for segmentation. For healthy mitral valve images, the user must choose from the range of images labelled normal_frame1 to normal_frame120. Similarly, the user will select from images labelled abnormal_frame1 to abnormal_frame203 for unhealthy mitral valve images. This selection process ensures that the user can pick the specific image they wish to segment from a predefined set of healthy or unhealthy mitral valve images. Once an image is selected, the system will automatically perform the segmentation process on the chosen image. The segmented result will be displayed in the “Segmented Image” section of the interface. This functionality will apply to healthy and unhealthy mitral valve images, giving users an immediate visual representation of the segmentation outcome. This automatic segmentation helps streamline the process and ensures consistency in analysing mitral valve images. Additionally, when the user presses the “Simulation” button, the system will enter a loop that segments all available healthy and unhealthy mitral valve images in sequence. During this simulation, the system will display three views for each image which the original image, the segmented image, and the overlapped result, where the segmentation is superimposed on the original image. This feature allows users to observe and compare the results across multiple images, facilitating a comprehensive evaluation of the segmentation performance.

5. Conclusion

The work succeeds in achieving its objectives, the system was developed to function properly, accurately processing and segmenting images using the clustering method. It can also display the processed image to the user in real time.

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Conflict of Interest

The authors declare no conflict of interest regarding the paper's publication.

Author Contribution

The authors confirm their contribution to the paper as follows: study conception and design: Muhammad Izzat Bin Omar, Nabilah Binti Ibrahim; data collection: Muhammad Izzat Bin Omar; analysis and interpretation of results: Muhammad Izzat Bin Omar; draft manuscript preparation: Muhammad Izzat Bin Omar, Nabilah Binti Ibrahim. All authors reviewed the results and approved the final version of the manuscript.

References

Abdulateef, S. & Salman, M. (2021) A Comprehensive Review of Image Segmentation Techniques, *Iraqi Journal for Electrical and Electronic Engineering*, 17, 166–175, <https://doi.org/10.37917/ijeee.17.2.18>

Schmitz, F., Mohamed, S., & Punjabi, P. P. (2019). Book Review: braunwald's heart disease: a textbook of cardiovascular medicine.

Dia Foto Film Scannen (n.d.). *Pixelcalculator*. Retrieved June 5, 2024, from <https://pixelcalculator.com/en>

Ouyang, D. (n.d.). *EchoNet-Dynamic: Interpretable AI for beat-to-beat cardiac function assessment*. Retrieved May 25, 2024, from <https://github.com/echonet/dynamic>

Hall, J. E. (2016). *Guyton and Hall Textbook of Medical Physiology, Jordanian Edition E-Book*. Elsevier Health Sciences.

Jan, J. (2019). *Medical image processing reconstruction and analysis: concepts and methods* (Second edition.). CRC Press.

Bushong, S. C. (2020). *Radiologic science for technologist's e-book: radiologic science for technologists e-book*. Elsevier Health Sciences.