# SEGMENTATION AND TRACKING OF INFERIOR VENA CAVA IN ULTRASOUND IMAGES USING A NOVEL POLAR ACTIVE CONTOUR ALGORITHM


- Ebrahim Karami, Mohamed Shehata, and Andrew Smith

- Electrical and Computer Engineering, Memorial University, Canada
- Faculty of Medicine, Memorial University, Canada

# INTRODUCTION

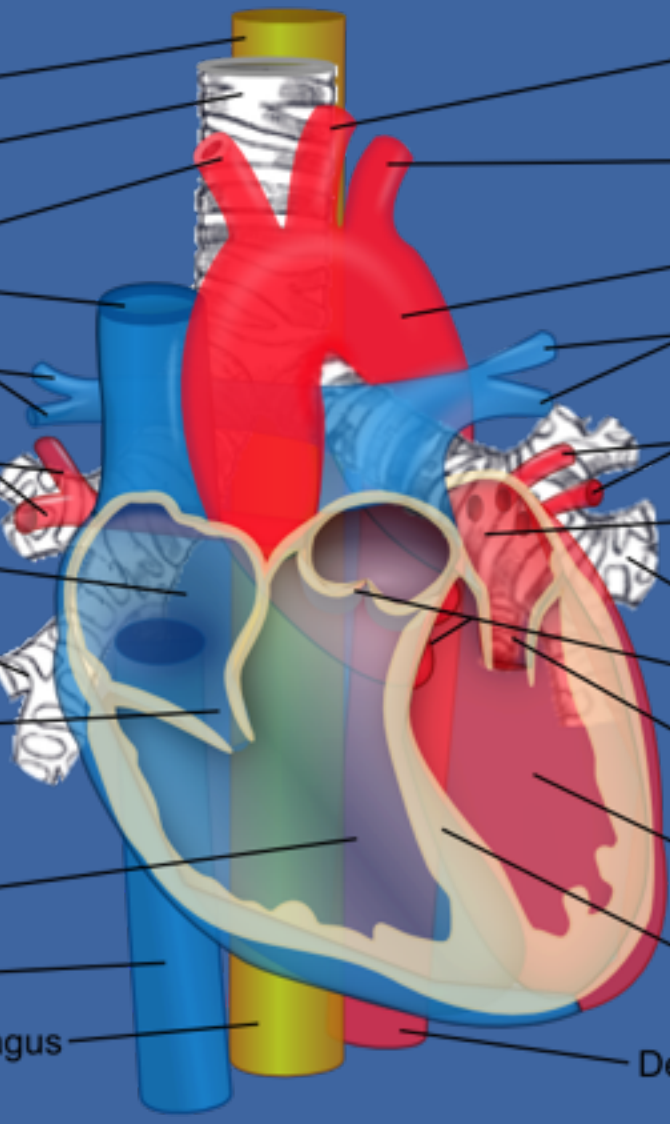
- Traditional methods of blood volume assessment are invasive and are recognized as poor predictors of fluid-responsiveness.

- Research has shown that respiratory variation in the inferior vena cana (IVC) resulting in changes in the anterior-posterior (AP) diameter is useful to predict fluid responsiveness.

- AP diameter of IVC and its variations can be measured from ultrasound images.

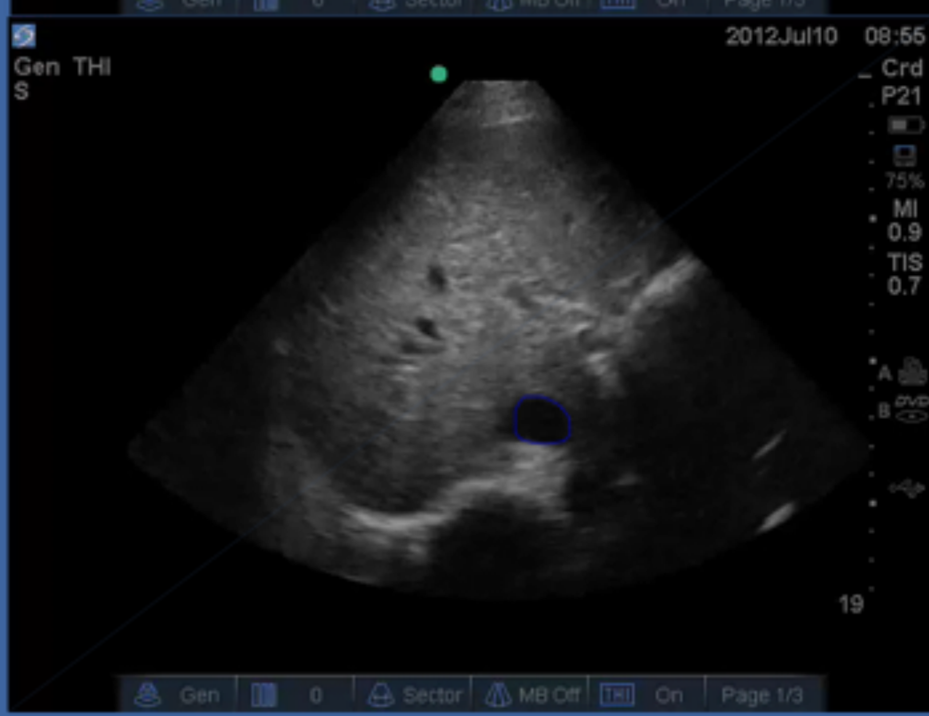
# INFERIOR VENA CAVA (IVC)

- The largest vein in the human body
- Close to heart
- React quickly to change in heart function
  - Size, distendability and shape
- Can be examined via ultrasound at bedside



# SAMPLE IVC IMAGES



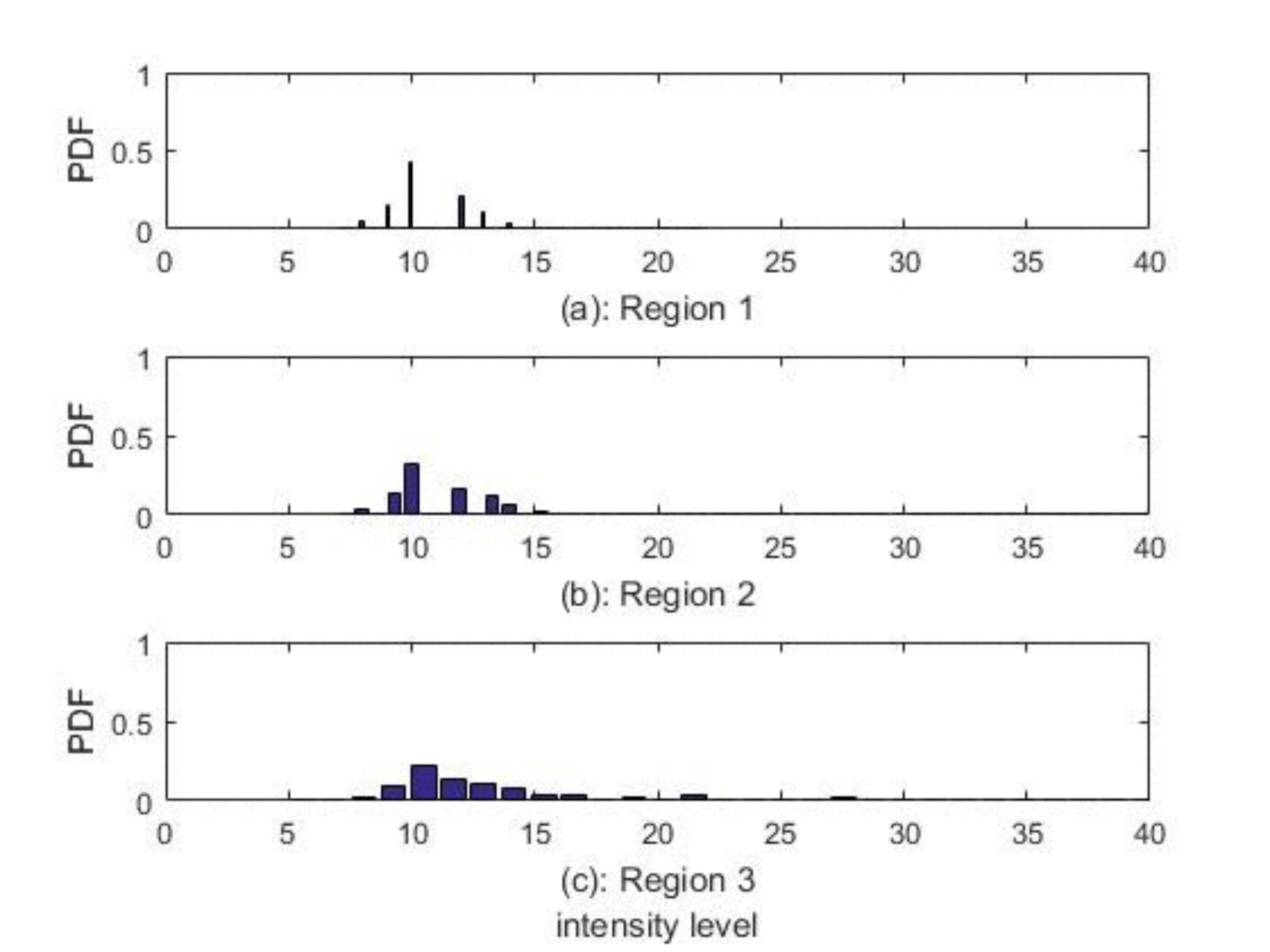



# IVC IMAGE STRUCTURE

- **Boundaries are Fuzzy, hence, edge-based segmentation techniques are not applicable.**

- **The intravascular region is largely hypo-echoic and extravascular hyper-echoic resulting in regional distributions with different means. But experiments show that they are not Rayleigh distribute.**

# MOTIVATION TO USE M3




PDF of the intensity levels inside the disks concentric with a the IVC with radius equal to (a): 80%, (b): 100%, and (c): 120% of the IVC.

# GOAL OF OUR RESEARCH

**Manual segmentation is a tedious and time-consuming task and therefore, it is inappropriate for real-time blood-volume monitoring.**

**Its results are also different from one operator to another.**

**In this research, we aim to propose a fast and reliable semi-automatic algorithm to segment IVC in ultrasound images.**

# PREVIOUS WORK

**Template matching cascaded with an active contour algorithm.**

K. Nakamura, et al., 2013, proposed simple template-matching cascaded with active contour for this problem.

## Drawback:

**Template matching is applicable only if deformation from one frame to the next one is negligible.**

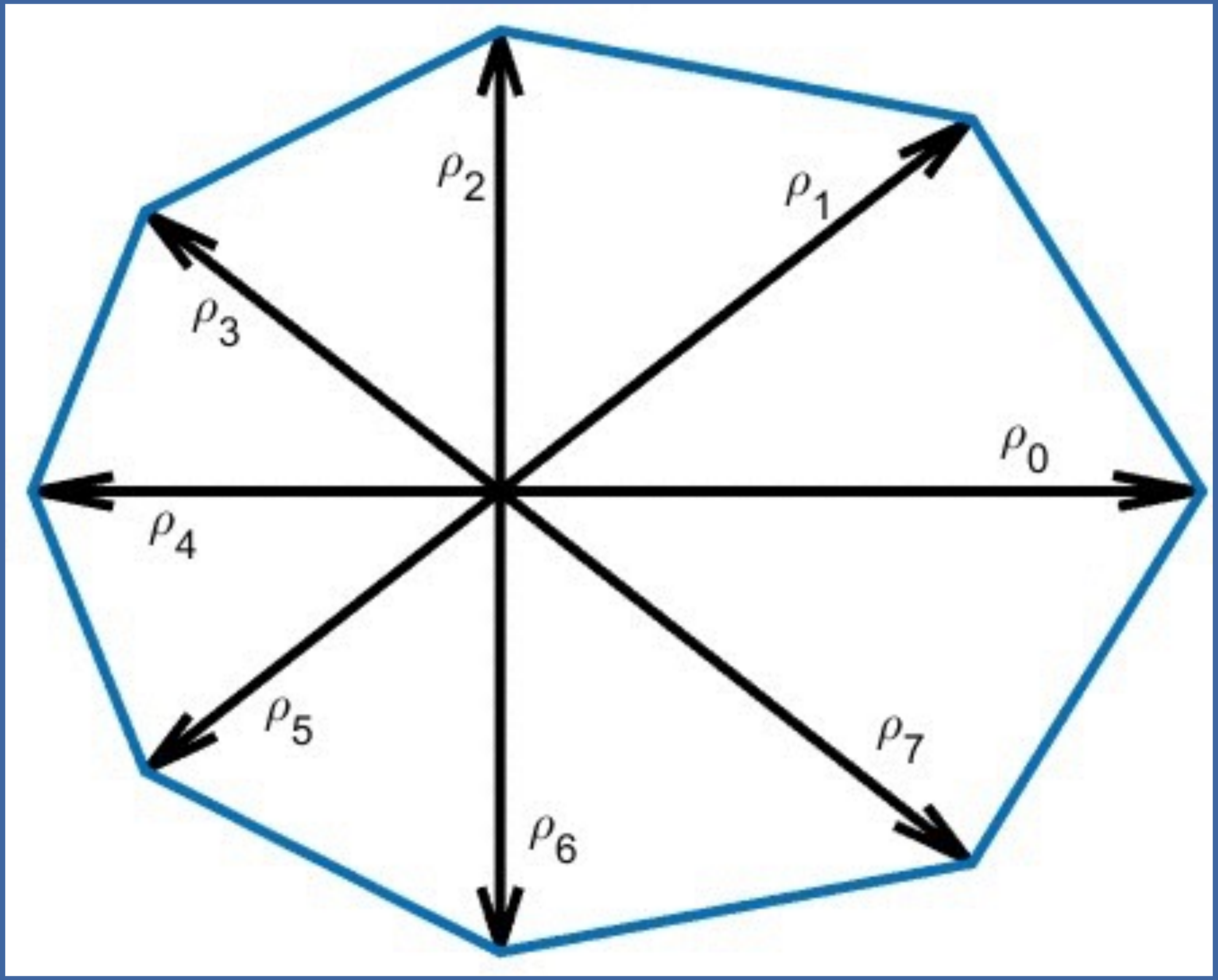
MEMORIAL UNIVERSITY

# WHY POLAR?

Cartesian active contours are defined as a set contour points $(x_i, y_i)$. For example for a 64 points contour the degree of freedom is 128. For a convex object the actual degree of freedom is less than this values. For example, with polar presentation the degree of freedom is N+2=66.

MEMORIAL UNIVERSITY

# POLAR PRESENTATION OF THE CONTOUR

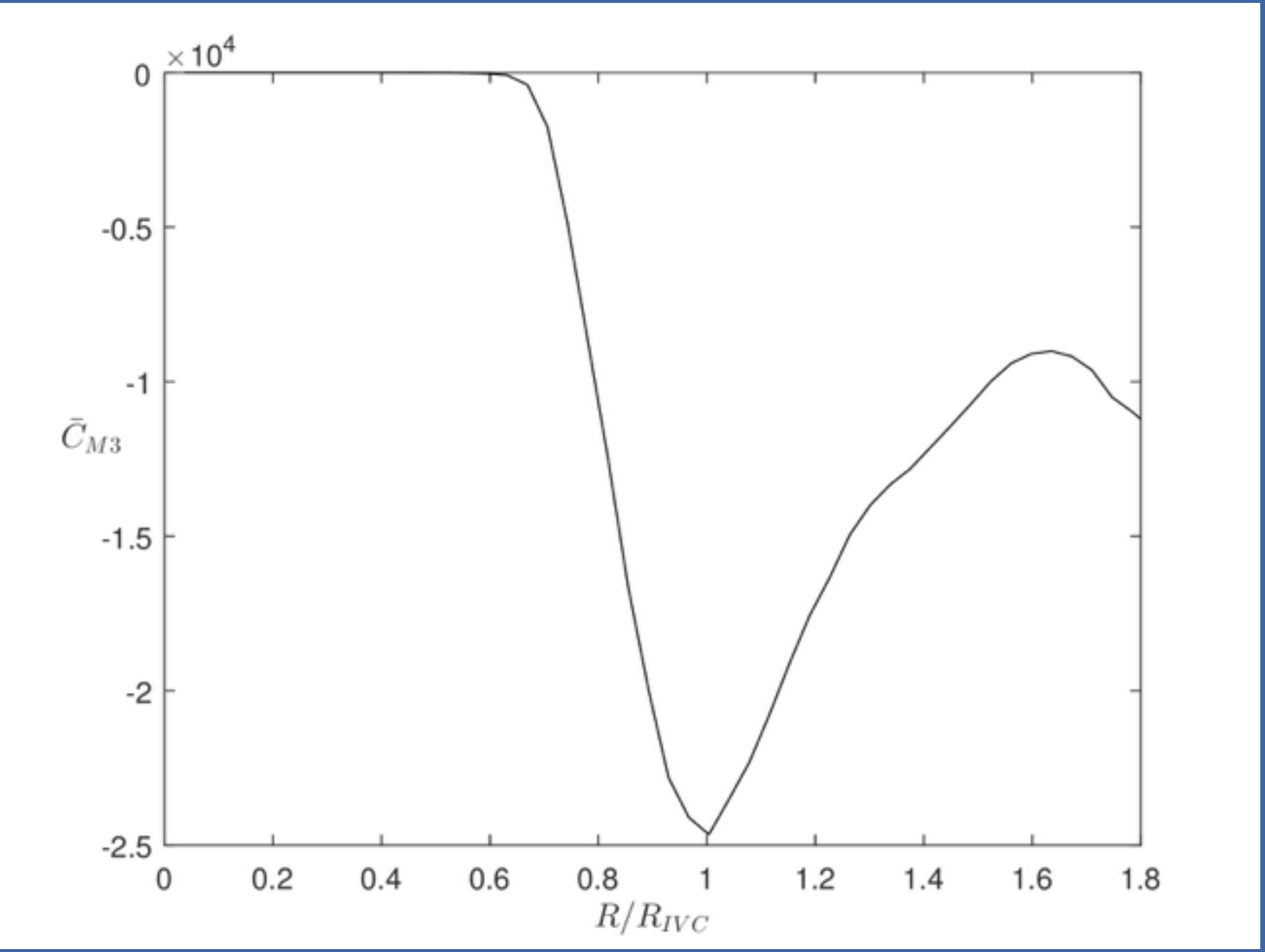



An example of polar contour with 8 contour points.

# PROPOSED ALGORITHM

Proposed energy functional is defined as:
$E = E_{M3} + E_{curv}$,
where $E_{M3} = -\alpha M_3$ and $M_3$ is
the 3rd centralized moment of the object,
and $E_{curv}$ is obtained as:
$E_{curv} = \beta \sum_{n=0}^{N-1} |p_{n_{+1}} - 2p_n + p_{n_{-1}}|^2$.

# WHY M3?




EM3 inside a circular contour C versus the normalized radius.

MEMORIAL UNIVERSITY

# EVOLUTION FUNCTIONAL FOR M3

The gradient of $E_{M3}$ versus $\boldsymbol{\rho} = [\rho_0, \rho_1, ..., \rho_{N-1}]^T$ is obtained as

$$\frac{\partial E_{M3}}{\partial \boldsymbol{\rho}} = \boldsymbol{A_c \rho},$$

where $\mathbf{A}_c$ is a tri-diagonal matrix defined as follows,

$$a_c(i,j) = \begin{cases} \kappa_n, & \text{if} \quad mod(|i-j|, N) = 1, \\ 0, & \text{otherwise}, \end{cases}$$

with $\kappa_n$ defined as

$$\kappa_n = \alpha_0[(I(p_n) - u)^3 - M_3 - 3(I(p_n) - u)M2],$$

where $\alpha_0 = -0.5\alpha \sin(\phi_0)$ and $I(p_n)$ is the pixel intensity at contour point $p_n$.

MEMORIAL UNIVERSITY

# EVOLUTION FUNCTIONAL FOR CURVATURE

$$\frac{\partial E_{curv}}{\partial \boldsymbol{\rho}} = \boldsymbol{B_c}\boldsymbol{\rho},$$

where $\mathbf{B}_c$ is a penta-diagonal matrix defined as follows,

$$b_c(i,j) = \begin{cases} 2\beta\cos(2\phi_0), & \text{if} \quad mod(i-j,N)=2, \\ -8\beta\cos(\phi_0), & \text{if} \quad mod(i-j,N)=1, \\ 12\beta, & \text{if} \quad i=j, \\ -8\beta\cos(\phi_0), & \text{if} \quad mod(j-i,N)=1, \\ 2\beta\cos(2\phi_0), & \text{if} \quad mod(j-i,N)=2, \\ 0, & \text{otherwise.} \end{cases}$$

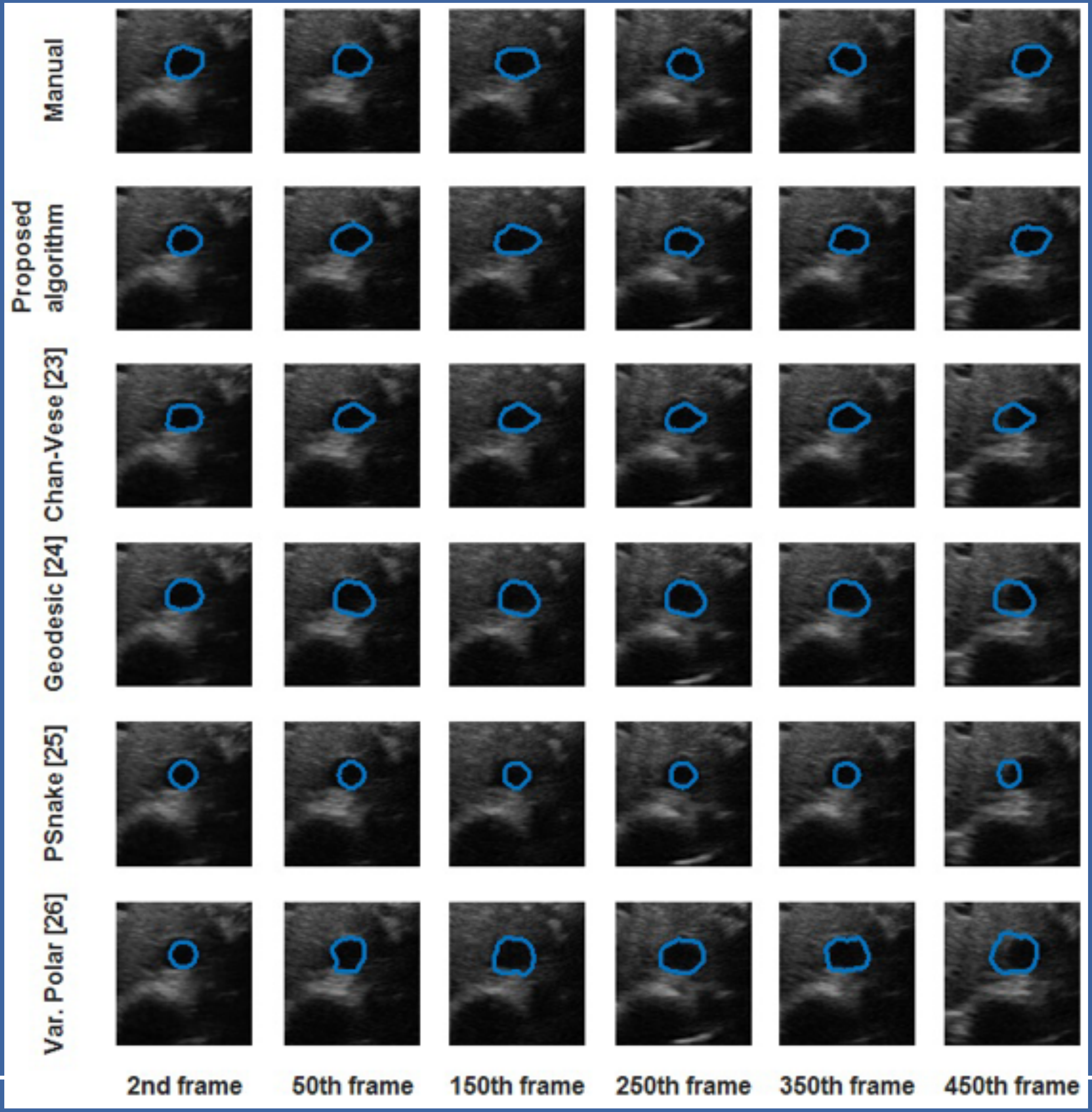
# PROPOSED POLAR AC ALGORITHM

**Input:** The center of IVC in the initial frame and parameters $\alpha$ and $\beta$ and $\mu$ and initial vector $\boldsymbol{\rho}_{(0)}$. In this research, we set them as $\alpha = 25$, $\beta = 0.025$, $\mu = 0.01$, and $\boldsymbol{\rho}_{(0)} = 12 \times \mathbf{1}_{N\times 1}$, where $\mathbf{1}_{N\times 1}$ is $N \times 1$ all-ones vector.
Step 1 - Read the first frame from the video.
Step 2 - Manually select the center of the first frame.
Step 3 - Update $\boldsymbol{\rho}$.
Step 4 - Repeat Step 3 until the algorithm reaches to the equilibrium condition. The equilibrium condition is defined as the condition where the maximum absolute value of change in $\boldsymbol{\rho}$ at the previous step is less than $10^{-3}$ pixels.
Step 5 - Return to step 3 for the next frame.

# RESULTS

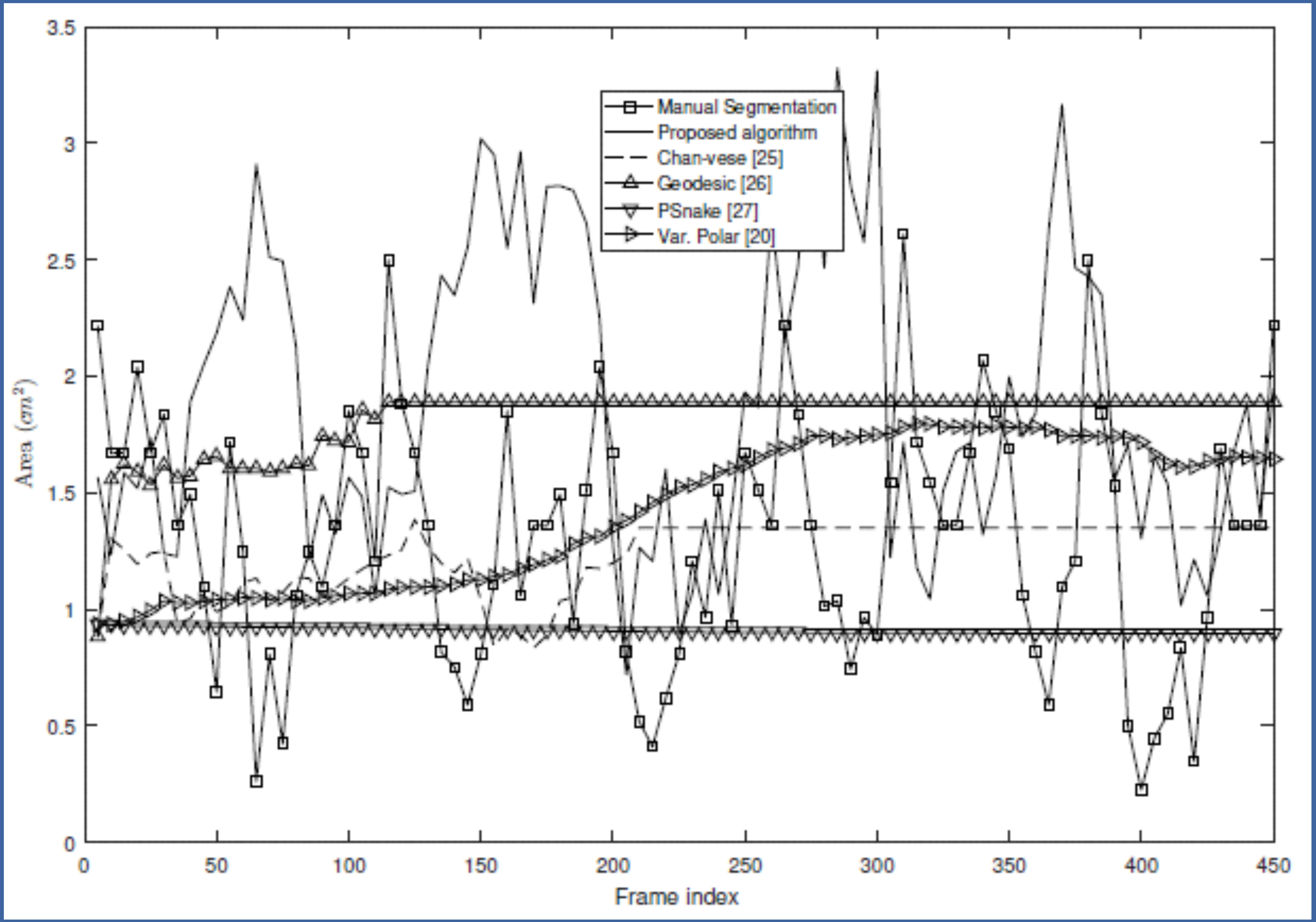
- The experimental data was collected from two healthy subjects after ethics approval was granted.
- The IVC was imaged in the transverse plane using a portable ultrasound (M-Turbe, Sonosite-FujiFilm) with a phased-array probe (1-5 Mhz).
- Each video has a frame rate of 30 fps, scan depth of 19cm, and a duration of 15 seconds (450 frames/clip).
- The proposed algorithm was also compared with expert manual segmentation, two classic AC algorithms - Chan-Vese and Geodesic, and two state-of-the-art polar ACs- PSnake and variational polar AC.

# RESULTS: TRACKING PERFORMANCE




MEMORIAL UNIVERSITY

# RESULTS: IVC AREA




IVC area as measured by the proposed algorithm, manual segmentation, and four other algorithms.

MEMORIAL UNIVERSITY

# CONCLUSION AND FUTURE WORK

1. A polar active contour based on M3 moment was proposed for segmentation and tracking of IVC.
2. It was shown the proposed algorithm outperforms existing active contour algorithms.
3. As the future work, authors intend to extend the proposed M3 moment-based functional as a 3D IVC segmentation technique.