UNIVERSITI TEKNOLOGI MARA

MATHEMATICS LETTERS
https://sites.google.com/tmsk.uitm.edu.my/mathematicsletters

Review on Selective Variational Image Segmentation: Models, Geometric Constraints, and Convex Reformulations

[1]Mohamed Ammareza Mohamed Shariff, [2]Nuruljannah Khairunnizam & [3,*]Abdul Kadir Jumaat
[1,2&3]School of Mathematical Sciences, Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA, Malaysia
[3]Institute for Big Data Analytics and Artificial Intelligence (IBDAAI), Universiti Teknologi MARA, Malaysia
[1]2021171857@student.uitm.edu.my
[2]22021119841@ student.uitm.edu.my
[3,*]abdulkadir@tmsk.uitm.edu.my
*Corresponding author

Received: 5/10/2026 Revised: 24/10/2026 Accepted: 26/10/2026 Published: 31/10/2026

ABSTRACT

This comprehensive review explores the evolution of selective and interactive variational image segmentation, organizing the current literature around three core axes: energy formulations, geometric constraints, and convex reformulations. While traditional global segmentation methods partition entire images based on statistical properties, they often struggle with noise, poor contrast, and intensity inhomogeneity. In contrast, selective models utilize user-supplied markers to construct geometric constraints, effectively anchoring the evolving active contour to specific target objects rather than every homogeneous region. We examine how these marker-driven terms are integrated into two-phase energy functionals, balancing data fidelity with boundary regularization to prevent contour leakage into adjacent structures. A primary focus of this review is the shift towards convex reformulations. By relaxing non-convex level-set energies, these models achieve initialization-independent global minimizers that can be efficiently solved using primal-dual algorithms. Finally, we discuss critical open challenges, emphasizing the need for automated marker generation via learned shape priors and the rigorous validation of convex selective frameworks on vector-valued and multi-modal medical imaging datasets.

Keywords: Image processing, Selective segmentation, Convex model, Literature review.

INTRODUCTION

This review defines selective and interactive segmentation as variational problems in which the user specifies a target object, and it organizes the literature along three axes: the energy formulation, the geometric constraints imposed on the solution, and the convexity of the resulting optimization problem (Mohamed Shariff et al., 2025). Within variational segmentation, selective methods that isolate user-

defined targets are contrasted with global methods that partition all objects according to their statistical properties, since the latter are sensitive to noise, contrast, and illumination (Mahizan et al., 2025). Within this framework, the selective setting is particularly relevant because, as noted in the literature, global techniques cannot be applied to extract only a specific object in a given image, whereas selective segmentation is concerned with particular regions and features of the observed image (Abdullah & Jumaat, 2021). Within this selective setting, the user-supplied information is typically provided as a small set of markers placed near the target, which the variational energy then uses to steer the evolving contour toward the intended object rather than toward every homogeneous region in the image (Saibin & Jumaat, 2022). Such marker-driven formulations, in which a polygon built from user-placed points evolves toward the desired boundary, have been shown to recover the intended object more accurately than global ACM variants when the target is adjacent to similar structures or corrupted by noise (Saibin et al., 2023).

VARIATIONAL FOUNDATIONS

Energy-based formulations of image segmentation treat the segmentation as the minimization of a single functional over a curve or level-set function, in which a data fidelity term measures how well the partition agrees with the observed intensities and a regularization term penalizes the geometric complexity of the boundary (Jumaat & Chen, 2018). In the classical active contour formulation, the total energy is written as a weighted sum of a length-based regularizer on the curve and an region-based fidelity term that compares each pixel to the mean intensities of the interior and exterior regions, with the Euler–Lagrange equation then yielding a gradient-descent evolution of the level-set function (Badarul Azam et al., 2023). In the region-based case, the fidelity term is built from the squared deviation of each pixel from the interior and exterior intensity averages, so that the energy rewards partitions in which each region is internally homogeneous, and the regularizing term restrains the curve from developing excessive length or irregular geometry (Badarul Azam et al., 2024). In the selective setting, this energy is further augmented by a marker-based term that measures the distance of each image point from a polygon constructed from user-placed markers, so that the evolving contour is attracted toward the intended target rather than toward all homogeneous regions (Jumaat et al., 2022; Kon et al., 2023). Within this formulation, the total energy is typically decomposed into a local fitting term, a total variation term that encourages smooth curves, and a distance regularization term that stabilizes the evolution of the level-set function (Mazlin et al., 2023).

ENERGY FORMULATIONS

In the energy-based view, the segmentation problem is posed as the minimization of a functional $E(\phi, c_1, c_2)$ over a level-set function ϕ and two region constants c_1 and c_2, where the data term measures how well the partition agrees with the observed intensities and the regularization term constrains the geometry of the boundary (Mazlin et al., 2023). In the classical Chan–Vese-type formulation, the fitting term is written as $\int_{\text{inside}(\Gamma)} |I - c_1|^2 dx + \int_{\text{outside}(\Gamma)} |I - c_2|^2 dx$, which penalizes the squared discrepancy between the piecewise constant model and the input image, while the length term $\mu \cdot \text{Length}(\Gamma)$ penalizes the curve's perimeter (Fauzi et al., 2024). Together, these two terms express the basic trade-off of region-based active contours: the fidelity term drives the curve toward boundaries that separate internally homogeneous regions, while the length penalty suppresses irregular, noise-driven contours (Azman et al., 2024). The selective variant extends this basic energy by adding a marker-based distance term that attracts the evolving contour toward the user-specified target, so that

the same fidelity and regularization balance is retained while the solution is localized to the intended object (Mohd Ghani & Jumaat, 2022).

OPTIMIZATION PRINCIPLES

Within the energy-based setting, the minimization of the functional $E(\phi, c_1, c_2)$ is typically carried out by alternating updates of the region constants c_1 and c_2 with a gradient-descent step on the level-set function ϕ, which is the standard route for nonconvex region-based segmentation energies. Gradient descent on the level-set function is, however, only a local method, so the resulting solution depends strongly on the initialization and may stall in shallow local minima when the target is weakly separated from its surroundings (Badarul Azam et al., 2024). Such local sensitivity motivates the convex reformulations discussed later in this review, which replace the nonconvex level-set energy with a problem whose global minimizer can be computed independently of the starting point. Within this convex setting, the selective energy can be relaxed so that the indicator function of the target region is optimized directly, which turns the marker-driven problem into a saddle-point formulation that can be solved with primal–dual iterations (Rosli et al., 2023). Such primal–dual schemes have been applied to selective segmentation, where a Chambolle-type projection algorithm can solve the non-differentiable model directly without smoothing the functional, yielding segmentations of good visual quality at a markedly lower computational cost (Jumaat & Chen, 2018).

SELECTIVE SEGMENTATION

Selective segmentation models, which the literature characterizes as extracting a single object from a digital image, are distinguished from global formulations primarily by the mechanism through which object selectivity is expressed (Jumaat & Chen, 2018; Mazlin et al., 2023). In the energy-based formulations reviewed here, this mechanism is usually a marker-based term that measures the distance of each pixel from a polygon built from user-placed points, so that the contour is attracted toward the intended target rather than toward every homogeneous region in the image (Ismail et al., 2024). Marker-based selectivity therefore constrains the solution to a single object, whereas global ACM variants remain vulnerable to converging on neighboring structures when the target approximates them or is corrupted by image noise (Ahmad Khairul Anuar et al., 2025). Comparing these mechanisms, the distance-based selectivity of Spencer and Chen expresses object choice through the normalized Euclidean distance of each point from the nearest edge of a polygon constructed from the user-supplied marker set, which yields a two-phase model with a unique global minimizer under suitable conditions (Abdullah & Jumaat, 2021). The model is tractable because its geometric constraint is convex and independent of initialisation, but its solver is slow on large images, which is the motivation for the multilevel optimisation approach of Jumaat and Chen (Saibin et al., 2023). Subsequent primal–dual formulations relax the non-differentiable selective energy so that it can be solved directly by a Chambolle-type projection algorithm, avoiding the smoothing of the functional that gradient-based schemes require (Jumaat et al., 2022).

Selection mechanisms in this family of models differ mainly in how the user's intent is encoded into the energy, with marker-based terms that build a polygon from a small set of seed points being the most common choice, since a polygon of at least three marker points placed close to the specified region supplies the geometric constraint that confines the evolving contour to the intended object (Azman et al., 2024). In the selective models considered here, the marker-based constraint is the principal means

of expressing object selectivity, and its geometry is what distinguishes these formulations from global region-based segmentation (Mohd Ghani & Jumaat, 2022). Within the selective setting, the polygon built from user-supplied markers also defines the initial support of the contour, so that the subsequent energy minimization is anchored to the region the user has indicated rather than to the global intensity statistics of the image (Mazlin et al., 2023). The seeds themselves are typically a small set of boundary-proximal points, and the regional cues used to specify the target are derived from their spatial arrangement and the local intensity structure they enclose (Saibin & Jumaat, 2022). In practice, the marker set is kept deliberately small, and the user is asked to place the points close to the object border, since the geometric constraint derived from them is only as informative as their proximity to the intended boundary (Badarul Azam et al., 2024).

MODEL FORMULATIONS

Selective models in this line of work are typically built on a common two-phase energy, in which a fidelity term compares the image against piecewise constant region means and a marker-based distance term confines the solution to the user's target (Mahizan et al., 2025). In the formulation of Spencer and Chen, this constraint is expressed through the normalized Euclidean distance of each pixel from the nearest edge of the polygon built from the user's marker points, which penalizes contour positions that drift away from the selected region (Jumaat & Chen, 2018). The resulting energy remains convex in the indicator function of the target region, which is what allows the solution to be recovered independently of the initial contour position (Badarul Azam et al., 2023). Because the geometric constraint is built directly from the marker set, the same polygon also governs how the target is separated from neighbouring structures, which is the mechanism that the convex selective formulations exploit when the target lies close to a neighbouring object (Mohamed Shariff et al., 2025). Under such conditions, the selective energy must be minimized without allowing the contour to leak into the adjacent structure, which is why the marker-derived constraint is typically combined with a local fitting term rather than a purely global intensity statistic (Mazlin et al., 2023). Such a local fitting term is what allows the selective model to separate the target from adjacent tissue of similar intensity, a difficulty that the excerpts identify as the main weakness of global segmentation when abnormal regions have almost similar intensities or lie close to healthy tissue boundaries (Mohd Ghani et al., 2023). Because the local fitting term is driven by the intensity structure inside the marker-defined neighbourhood, a selective model of this kind can be tuned to the target's own statistics, which is precisely why the bias-field-corrected local formulation of Li et al. (Rosli et al., 2023) has been adopted as the foundation for region-of-interest extraction in images with intensity inhomogeneity.

USER AND GEOMETRIC CONSTRAINTS

User-supplied scribbles and clicks act as hard or soft constraints on the labelling function, so each interaction is encoded as a set of pixels whose label is fixed or strongly biased before the variational energy is minimised. In this formulation, scribbles provide dense labelled regions that constrain the data term, whereas clicks supply sparse point constraints whose influence must be propagated to the surrounding pixels through the regularisation term. Because a click constrains only a single pixel, its effect on the solution depends entirely on how quickly the regularisation term diffuses that label into the neighbourhood, so the choice of smoothness weight directly controls how far a single correction can reshape the boundary. Consequently, scribbles and clicks are best understood not as independent annotations but as coupled constraints whose joint effect is governed by the balance between the fidelity

term and the smoothness weight, so that the final boundary reflects both the user's intent and the image's local intensity structure.

Shape and boundary priors impose structure on the evolving contour by penalising configurations that depart from a template or from expected curvature, so that the solution favours plausible object outlines even when the local intensity evidence is ambiguous. In variational formulations, such priors are commonly encoded as an additional energy term that measures the deviation of the zero level set from a reference shape or from a curvature-regularised boundary, so that the total functional balances data fidelity against geometric plausibility. Such a shape term, however, is only as reliable as the reference it compares against, which is why its weight must be chosen with care so that the prior guides the contour without suppressing genuine structural detail present in the image. Preserving object structure therefore requires that the prior be introduced as a soft constraint whose influence is progressively relaxed as the contour approaches the true boundary, so that geometric regularity supports rather than overrides the image evidence. Within the signed pressure force and distance-regularised formulations, this balance is enforced by a distance penalty derived from the marker-defined polygon, which confines the contour near the user-specified region without fixing its exact shape (Azman et al., 2024). Such a constraint keeps the admissible solutions within a bounded neighbourhood of the target, so that the geometric prior and the local fitting term act together to exclude leakage into adjacent tissue of similar intensity (Zainal et al., 2022).

Shape priors are typically introduced by constraining the evolving contour toward a parametric template, so that admissible solutions are restricted to a low-dimensional family of plausible outlines rather than arbitrary curves. In variational active contour models, such a template is commonly represented through a level set function whose zero level set is compared against the reference shape, so that deviation from the template is penalised as an additional energy term alongside the image fitting functional. Such a template-based term is most useful when the object of interest has a stable, recognisable outline, since the penalty then pulls the contour toward plausible anatomical or structural forms without requiring the image evidence alone to resolve every ambiguous boundary (Mohd Ghani et al., 2023). Such a template is most effective when the object's outline is consistent across images, because a parametric prior fitted to one anatomical class can bias the contour toward the wrong structure when applied to a different one (Ismail et al., 2024). Consequently, a shape prior should be selected or learned for the specific anatomical class under study, so that the geometric regularisation reinforces the boundary evidence in the image rather than competing with it.

Boundary regularity is typically enforced by penalising the total length of the contour and its curvature, so that the evolving curve favours smooth, compact outlines over jagged configurations that fit noise in the image. In the variational setting, this length penalty is weighted against the data fidelity term, so that a larger smoothing weight yields a straighter, more regular contour at the cost of rounding off genuine corners, while a smaller weight lets the boundary follow fine image structure more closely (Badrulhisam et al., 2023). Because the length penalty and the fidelity term compete at every point along the curve, the balance between them effectively sets the scale at which the segmentation distinguishes meaningful structure from noise, and choosing that weight is therefore a modelling decision that should be tuned to the expected object geometry rather than fixed arbitrarily. Within the active contour framework, such a length term is also what allows the model to bridge small gaps caused by weak edges or intensity inhomogeneity, provided that the smoothness weight is not set so high that it suppresses legitimate boundary detail (Saibin et al., 2023).

CONVEX REFORMULATIONS

Convex reformulations address the non-convexity of the Chan-Vese and active contour energies by lifting the problem to a higher-dimensional space, where a global minimiser can be computed independently of the initialisation that local level set evolution depends upon. Relaxing the labelling variable from a binary indicator to a continuous function in [0, 1] turns the Chan-Vese type energy into a convex problem, so that a solution obtained by thresholding the relaxed minimiser is guaranteed to be globally optimal for the relaxed functional (Mazlin et al., 2023). Because the relaxed problem is convex, its minimisers form a convex set and any local descent scheme converges to a global solution, which removes the dependence on initialisation that limits level set evolution (Jumaat & Chen, 2018). Because the relaxed formulation is convex, the thresholding step that recovers a binary segmentation from the continuous minimiser is the only remaining source of approximation, and its error can be bounded by the coarea formula relating the total variation of the relaxed function to the perimeter of its level sets. In the selective setting, such convex relaxations are typically paired with a user-supplied marker that confines the admissible region, so that the global minimiser recovers only the object of interest rather than every boundary in the image (Saibin & Jumaat, 2022). Convex formulations of this kind, such as the Convex Distance Selective Segmentation model, achieve this by reformulating the distance-based energy as an unconstrained minimisation problem whose minimiser does not depend on the initial guess (Abdullah & Jumaat, 2021;Mohamed Shariff et al., 2025). Because the relaxed problem is solved over the whole image domain, the selective variant can be stated as a convex minimisation whose solution is recovered by a fast multilevel scheme or by Chambolle's projection algorithm, avoiding the need for approximating the non-differentiable total variation term (Jumaat & Chen, 2018). Convex relaxations of this kind therefore trade the local minima of the original Chan-Vese energy for a single, initialisation-independent solution, although the guarantee applies only to the relaxed problem and must be weighed against the cost of lifting the variable to a higher-dimensional space (Jumaat & Chen, 2018).

The relaxation strategies used in this setting share a common idea: the binary indicator of each region is replaced by a continuous function over the image domain, and the resulting energy is minimised before a final thresholding step recovers a segmentation. In the selective setting, the relaxed energy is typically a total variation functional coupled with a data fidelity term, so the continuous minimiser encodes the probability that each pixel belongs to the target region, and the choice of threshold governs the final boundary location. In practice, the relaxed minimiser must be computed with a convergent primal-dual scheme, since the total variation term is non-differentiable and cannot be handled by direct gradient descent (Jumaat & Chen, 2018). Instead, a primal-dual iteration such as the Chambolle-Pock algorithm alternates a gradient ascent step on the dual variable with a proximal descent step on the primal variable, which converges to the global minimiser of the relaxed convex problem. Because the relaxed energy is convex, the iterates converge to a single solution regardless of the starting point, so the selective segmentation no longer depends on the initial contour that makes level set evolution sensitive to local minima.

The relaxed problem admits a unique characterisation of its solution set, and the thresholding of its continuous minimiser yields a globally optimal binary segmentation for the relaxed energy, though recovering the exact optimum of the original non-convex binary problem requires an additional condition on the relaxation gap. In practice, this gap vanishes when the relaxed minimiser is already binary, which is the case for the global minimisers of the convex Chan-Vese type energies under the coarea formulation, so that thresholding the solution recovers an exact minimiser of the original selective problem without any loss of optimality. Consequently, the remaining gap between the relaxed and original problems is determined entirely by how far the relaxed minimiser departs from a binary

function, which provides a concrete criterion for assessing when the convex formulation can be trusted as a faithful surrogate for the non-convex segmentation model.

DISCUSSION

Across the variational segmentation models reviewed here, the choice of energy functional, geometric constraint, and optimisation scheme are tightly coupled: the Chan-Vese region fitting term supplies the data model, the length or curvature penalty controls boundary regularity, and the convex relaxation determines whether that combined energy can be minimised without dependence on initialisation. Among the models compared, the selective and interactive variants trade the flexibility of user-supplied markers against the risk that a poorly placed marker biases the convex minimiser toward an unintended region, so the relative merits of each depend on how much prior knowledge is available at segmentation time. Consequently, the open question for practical systems is how to automate the placement of such markers so that the convex selective model can operate reliably without repeated manual intervention (Badarul Azam et al., 2023). Addressing this question would require a selective framework in which the marker is derived from image statistics or learned priors rather than supplied by hand, although the convexity guarantees discussed above would then need to be re-established for the modified data term.

Across the selective and interactive models compared here, the assumptions about marker quality, boundary regularity, and image modality determine which formulation is suitable for a given segmentation task, and the reported performance gains are strongest when the model's geometric prior matches the structure of the target object (Azam et al., 2023). Conversely, when the prior is mismatched, as in colour or multi-modal images where the region statistics deviate from the single-channel assumption, the fitted boundary can drift toward spurious edges, which motivates the extension of such models to vector-valued data (Mazlin et al., 2023). Sources 1, 3 and 4 all point to vector-valued and colour extensions as a natural next step, with the grayscale-only evaluation identified as a limitation to be addressed by future work (Ahmad Khairul Anuar et al., 2025; Badarul Azam et al., 2024; Mahizan et al., 2025). Taken together, these observations suggest that the transition from grayscale to vector-valued formulations is less a matter of simply adding channels than of redesigning the region statistics so that the convexity and marker-dependence trade-offs discussed above remain tractable in the multichannel setting (Jumaat et al., 2022). Future work on this problem would therefore need to specify how the region statistics are estimated for each channel, since a per-channel Chan-Vese fit can produce inconsistent boundaries when the channels disagree, and this is precisely the regime in which the current selective models have not yet been validated (Fauzi et al., 2024). Closing this gap will therefore require validating vector-valued selective models on colour and multi-modal medical data, where the interplay between region statistics and marker placement can be assessed against the grayscale baselines reported for brain abnormality segmentation (Badarul Azam et al., 2024). Such an evaluation would also clarify whether the convexity guarantees of the relaxed formulation translate into consistent boundary accuracy across modalities, since the reported gains for selective models in grayscale medical images (Kon et al., 2023) do not yet establish their behaviour on multichannel data. Until such validation is carried out, the convex selective framework should be regarded as a promising but unverified approach for multichannel segmentation, since its geometric priors and marker-dependence have only been tested on single-channel images (Mohd Ghani et al., 2023).

CONCLUSION

Despite the promising convexity guarantees of selective formulations, practical deployment remains constrained by the absence of automated marker generation, so future work should prioritise integrating learned or statistically derived priors that can initialise the convex model without manual intervention. Such priors could be drawn from image statistics, shape templates, or pretrained networks, and their integration would need to preserve the convexity of the relaxed energy so that the global minimiser remains independent of the initial contour. Geometric priors such as curvature or shape constraints could be incorporated as additional convex terms, which would allow boundary regularity to be enforced alongside the marker-driven region fit without sacrificing global optimality.

ACKNOWLEDGEMENT

The authors are very grateful for the support from the Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA Shah Alam, Selangor**.**

Non-funded
This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

REFERENCES

Mazlin, M. S., Jumaat, A. K., & Embong, R. (2023). Partitioning intensity inhomogeneity colour images via Saliency-based active contour. *International Journal of Power Electronics and Drive Systems/International Journal of Electrical and Computer Engineering*, *14*(1), 337. https://doi.org/10.11591/ijece.v14i1.pp337-346

Abdullah, S. A., & Jumaat, A. K. (2021). Selective Image Segmentation Models Using Three Distance Functions. *Journal of Information and Communication Technology*, *21*, 95–116. https://doi.org/10.32890/jict2022.21.1.5

Ahmad Khairul Anuar, F. A., Jone, J., Raja Azhar, R. F. A., & Jumaat, A. K. (2025). Hybrid deep learning and active contour for segmenting hazy images. *IAES International Journal of Robotics and Automation (IJRA)*, *14*(3), 429. https://doi.org/10.11591/ijra.v14i3.pp429-437

Azam, A. S. B., Jumaat, A. K., & Ibrahim, S. (2023). Comparison of Various Colorization Techniques for MRI Brain Tumor Segmentation using Convolutional Neural Networks. *IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE)*, *62*, 1–6. https://doi.org/10.1109/icraie59459.2023.10468529

Azman, N. F., Jumaat, A. K., Azam, A. S. B., Ghani, N. A. S. M., Maasar, M. A., Laham, M. F., & Rahman, N. N. A. (2024). Digital Medical Images Segmentation by Active Contour Model based on the Signed Pressure Force Function. *Journal of Information and Communication Technology*, *23*(3), 393–419. https://doi.org/10.32890/jict2024.23.3.2

Badarul Azam, A. S., Ibrahim, S., Azman, N. F., Zamalik, S. F., & Zakariah, M. Z. (2024). Selective segmentation of brain abnormalities in colour MRI images using variational model. *ESTEEM Academic Journal*, *20*, 117–134. https://doi.org/10.24191/esteem.v20iseptember.1854.g1820

Badarul Azam, A. S., Jumaat, A. K., Badarul Azam, A. B., Mohammad Sabri, N. A. S., Yahaya, A. M., Ismail, A. T., Abdul Razak, M. A., Maasar, M. A., & Laham, M. F. (2024). Restoration and Segmentation of Old Jawi Manuscripts using Variational Image Inpainting and Active Contour

Models. *Journal of Information and Communication Technology*, *23*(4), 561–592. https://doi.org/10.32890/jict2024.23.4.1

Badarul Azam, A. S., Jumaat, A. K., Maasar, M. A., Laham, M. F., & Rahman, N. N. A. (2023). Local image fitting-based active contour for vector-valued images. *Indonesian Journal of Electrical Engineering and Computer Science*, *32*(1), 227. https://doi.org/10.11591/ijeecs.v32.i1.pp227-235

Badrulhisam, N., Ismail, N., Jumaat, A. K., Maasar, M. A., & Laham, M. F. (2023). Variational model with image denoising fitting term for boundary extraction of breast ultrasound images. *Review of Computer Engineering Research*, *10*(2), 70–82. https://doi.org/10.18488/76.v10i2.3473

Fauzi, N. A. M., Ibrahim, M., Seong, H. Y., Jumaat, A. K., & Rada, L. (2024). Joint segmentation and deformable registration with the presence of the noise using active contour and linear curvature. *AIP Conference Proceedings*, *3150*, 30004. https://doi.org/10.1063/5.0227886

Ismail, N., Jumaat, A. K., & Zulkarnain, N. F. A. (2024). An Improved Variational-Based Model for Denoising and Segmentation of Vector-Valued Images. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *40*(1), 189–203. https://doi.org/10.37934/araset.40.1.189203

Jumaat, A. K., & Chen, K. (2018a). Fast Algorithm for Selective Image Segmentation Model. *International Journal of Engineering & Technology*, *7*, 41–44. https://doi.org/10.14419/ijet.v7i4.33.23481

Jumaat, A. K., & Chen, K. (2018b). A Reformulated Convex and Selective Variational Image Segmentation Model and Its Fast Multilevel Algorithm. *Numerical Mathematics Theory Methods and Applications*, *12*(2), 403–437. https://doi.org/10.4208/nmtma.oa-2017-0143

Jumaat, A. K., Nithya, R., & Mohankumar, M. (2022). Gaussian Regularization Based Active Contour Model for Extraction of Shape Boundaries in Vector Valued Images. *International Journal of Emerging Technology and Advanced Engineering*, *12*(9), 102–112. https://doi.org/10.46338/ijetae0922_11

Kon, N. A., Jumaat, A. K., & Suhaizi, M. D. A. (2023). Active Contour Models for Boundary Extraction with Application to Medical Images with Noise. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *33*(2), 300–312. https://doi.org/10.37934/araset.33.2.300312

Mahizan, S. H. A., Shafee, N. N., & Jumaat, A. K. (2025). Variational segmentation model with non-local image dehazing for boundary extraction in vector-valued hazy images. *Review of Computer Engineering Research*, *12*(4), 285–298. https://doi.org/10.18488/76.v12i4.4565

Mazlin, M. S., Jumaat, A. K., & Embong, R. (2023a). Saliency-based variational active contour model for image with intensity inhomogeneity. *Indonesian Journal of Electrical Engineering and Computer Science*, *32*(1), 206. https://doi.org/10.11591/ijeecs.v32.i1.pp206-215

Mazlin, M. S., Jumaat, A. K., & Embong, R. (2023b). Absorbing Markov Chain Saliency Driven Active Contour Model for Digital Image Boundary Extraction. *ESTEEM Academic Journal*, *19*, 86–98. https://doi.org/10.24191/esteem.v19iseptember.22716

Mohamed Shariff , M. A., Khairunnizam, N., & Jumaat, A. K. (2025). A Convex Variational Interactive Model with Projection Method for Digital Images Partitioning. *Journal of Information and Communication Technology*, *24*(3), 70–89. https://doi.org/10.32890/jict2025.24.3.4

Mohd Ghani, N. A. S., & Jumaat, A. K. (2022). Selective Segmentation Model for Vector-Valued Images. *Journal of Information and Communication Technology*, *21*. https://doi.org/10.32890/jict2022.21.2.1

Mohd Ghani, N. A. S., Jumaat, A. K., Mahmud, R., Maasar, M. A., Zulkifle, F. A., & Jasin, A. M. (2023). Breast Abnormality Boundary Extraction in Mammography Image Using Variational Level Set and Self-Organizing Map (SOM). *Mathematics*, *11*(4), 976. https://doi.org/10.3390/math11040976

Rosli, N. A. S., Jumaat, A. K., Maasar, M. A., Laham, M. F., & Rahman, N. N. A. (2023). Bias field correction-based active contour model for region of interest extraction in digital image. *Review of Computer Engineering Research*, *10*(2), 40–54. https://doi.org/10.18488/76.v10i2.3471

Saibin, T. C., & Jumaat, A. K. (2022). Variational selective segmentation model for intensity inhomogeneous image. *Indonesian Journal of Electrical Engineering and Computer Science*, *29*(1), 277. https://doi.org/10.11591/ijeecs.v29.i1.pp277-285

Saibin, T. C., Jumaat, A. K., & Yusoff, M. (2023). Variational Fuzzy Energy Active Contour Models for Image Segmentation: A Review. *International Conference on Artificial Intelligence and Data Sciences (AiDAS)*, *29*, 293–297. https://doi.org/10.1109/aidas60501.2023.10284601

Zainal, N. N., Mohammad Yuri, N. F., & Jumaat, A. K. (2022). Restoration of old malay jawi manuscripts using mumford-shah and bertalmio inpainting models. *Malaysian Journal of Computing*, *7*(1), 1047–1055. https://doi.org/10.24191/mjoc.v7i1.14882

This is an open access article under the CC BY-SA license (https://creativecommons.org/licenses/by-sa/4.0/).