RGC Ref. No.:
UGC/FDS14/P04/15
(please insert ref. above)

RESEARCH GRANTS COUNCIL
COMPETITIVE RESEARCH FUNDING SCHEMES FOR THE LOCAL SELF-FINANCING DEGREE SECTOR

FACULTY DEVELOPMENT SCHEME (FDS)

Completion Report
(for completed projects only)

Submission Deadlines:
1. *Auditor's report with unspent balance, if any: within **six** months of the approved project completion date.*
2. *Completion report: within **12** months of the approved project completion date.*

Part A: The Project and Investigator(s)

1. Project Title

Fuzzy Generalized Gaussian Density Segmentation Model: Mathematical Analysis and Applications

2. Investigator(s) and Academic Department(s) / Unit(s) Involved

Research Team	Name / Post	Unit / Department / Institution
Principal Investigator	CHOY Siu-kai / Associate Professor	Department of Mathematics, Statistics and Insurance / The Hang Seng University of Hong Kong
Co-Investigator(s)	LAM Benson Shu-yan / Assistant Professor	Department of Mathematics, Statistics and Insurance / The Hang Seng University of Hong Kong
Others		

3. Project Duration

	Original	Revised	Date of RGC / Institution Approval *(must be quoted)*
Project Start Date	01 January 2016	01 January 2016	NA
Project Completion Date	31 December 2018	30 June 2019	16 October 2018
Duration *(in month)*	36	42	16 October 2018
Deadline for Submission of Completion Report	31 December 2019	30 June 2020	16 October 2018

Part B: The Final Report

5. Project Objectives

5.1 Objectives as per original application

1. To investigate a mathematical optimization framework that integrates the GGD model with the agglomerative fuzzy algorithm with spatial information.
2. To investigate the feasibility of the proposed segmentation algorithm and the mathematical theory that underpins it.
3. To conduct extensive experimental testing of the proposed method in various image segmentation applications.

5.2 Revised objectives

Date of approval from the RGC: NA

Reasons for the change: NA

5.3 Realisation of the objectives
(Maximum 1 page; please state how and to what extent the project objectives have been achieved; give reasons for under-achievements and outline attempts to overcome problems, if any)

All three project objectives have been achieved.

Objective 1: To investigate a mathematical optimization framework that integrates the GGD model with the agglomerative fuzzy algorithm with spatial information.

- We have developed a mathematical optimization framework that integrates GGD model, fuzzy algorithm and spatial information for image segmentation applications. The associated fuzzy GGD-based image segmentation model is constructed by integrating the GGD model with the fuzzy *k*-means clustering algorithm with neighboring information.

Objectives 2: To investigate the feasibility of the proposed segmentation algorithm and the mathematical theory that underpins it.

- We have developed an optimization procedure to minimize the fuzzy GGD-based image segmentation model based on the alternating minimization procedure. In addition, we have provided sufficient conditions for the existence of the GGD cluster center to justify the theoretical basis for its use.

Objective 3: To conduct extensive experimental testing of the proposed method in various image segmentation applications.

- We have developed the GGD-based agglomerative fuzzy algorithm and the unsupervised fuzzy GGD-based segmentation algorithm with neighboring information, and conducted extensive experiments on different kinds of images using public databases. Comparative experimental results with existing approaches show that our methods achieve remarkable success in image segmentation applications.

5.4 Summary of objectives addressed to date

Objectives *(as per 5.1/5.2 above)*	**Addressed** *(please tick)*	**Percentage Achieved** *(please estimate)*
1. To investigate a mathematical optimization framework that integrates the GGD model with the agglomerative fuzzy algorithm with spatial information.	✓	100%
2. To investigate the feasibility of the proposed segmentation algorithm and the mathematical theory that underpins it.	✓	100%
3. To conduct extensive experimental testing of the proposed method in various image segmentation applications.	✓	100%

6. Research Outcome

6.1 Major findings and research outcome
(Maximum 1 page; please make reference to Part C where necessary)

The major findings and research outcomes, which were published as in Part C, are shown below:

1. We have proposed a fuzzy Generalized Gaussian Density (GGD) segmentation model and the GGD-based agglomerative fuzzy algorithm for clustering image pixels. The merits of algorithm are that it is not sensitive to initial parameters and that the number of clusters can be estimated via the validation technique. To minimize the objective function of the model, we define a dissimilarity measure based on the Kullback–Leibler divergence of the GGDs that computes the discrepancy between GGDs in the space of generalized probability distributions. To effectively segment images with various textures, we propose a two-stage fuzzy GGD segmentation algorithm. The first stage adopts the proposed fuzzy algorithm to obtain initial segmentation and the second stage improves initial segmentation by image boundary correction. Experimental results show that our proposed method has a promising performance compared with existing approaches.

2. We have presented a novel unsupervised fuzzy model-based image segmentation algorithm. The proposed algorithm integrates color and GGD into the fuzzy clustering algorithm and incorporates their neighboring information into the learning process to improve the segmentation accuracy. In addition, a membership entropy term is used to make the algorithm not sensitive to initial clusters. To optimize the objective function of the proposed segmentation model, we define the dissimilarity measure between GGD models using the Kullback–Leibler divergence, which evaluates their discrepancy in the space of generalized probability distributions via only the model parameters. We also present mathematical analysis that proves the existence of the cluster center for the GGD parameters, thus establishing a theoretical basis for its use. Experimental results show that our proposed method has a promising performance compared with the current state-of-the-art fuzzy clustering-based approaches.

6.2 Potential for further development of the research and the proposed course of action *(Maximum half a page)*

The project can be further developed by studying the following aspects:

1. A few parameters in the algorithm need to be selected appropriately so as to achieve satisfactory results. An automate parameter selection methodologies should be investigated.
2. The GGD feature extraction is computationally expensive since this process is performed in an iterative mode and in a pixel-level. Thus, it would be a welcome advantage if a fast and effective model can be used to replace GGD to characterize image variations.
3. Instead of CIELAB color used in our experiments, it is expected that a more sophisticated state-of-the-art color model may enhance the segmentation accuracy.

7. Layman's Summary

(Describe in layman's language the nature, significance and value of the research project, in no more than 200 words)

The modeling of image histograms by a general parametric family of statistical distributions plays an important role in many applications. Many studies have shown that the histogram of image variations is symmetrical about zero and has a sharp peak at zero. This phenomenon motivates the use of a parametric family of known distributions such as Generalized Gaussian Density (GGD) to fit the observed histogram. The GGD model has been used as a model for the image variations and applied successfully to different areas. However, the use of GGD model for image segmentation has not been studied in the literature. Our proposed project is to study the mathematical optimization framework that integrates the GGD model with an agglomerative fuzzy algorithm with spatial information for image segmentation applications. We will also develop a rigorous mathematical analysis on the fuzzy GGD segmentation model. The performance of the proposed segmentation algorithm will be evaluated by extensive and comparative experiments on natural and texture images. Our proposed method is expected to assist researchers in the field of machine learning by providing a new model-based unsupervised learning algorithm with practical computer vision applications.

Part C: Research Output

8. Peer-Reviewed Journal Publication(s) Arising Directly From This Research Project
(Please attach a copy of the publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.)

The Latest Status of Publications				Author(s) *(denote the correspond-ing author with an asterisk*)*	Title and Journal / Book *(with the volume, pages and other necessary publishing details specified)*	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this Report *(Yes or No)*	Acknowledged the Support of RGC *(Yes or No)*	Accessible from the Institutional Repository *(Yes or No)*
Year of Publication	**Year of Acceptance** *(For paper accepted but not yet published)*	**Under Review**	**Under Preparation** *(optional)*						
2020				Choy Siu Kai*, Ng Tsz Ching, Yu Carisa	Unsupervised Fuzzy Model-based Image Segmentation (vol.171, Signal Processing)	**No**	**Yes**	**Yes**	**Yes**
2017				Choy Siu Kai*, Lam Shu Yan, Yu Kwok Wai, Lee Wing Yan and Leung King Tai	Fuzzy Model-based Clustering and Its Application in Image Segmentation (vol.68, pp. 141-157, Pattern Recognition)	**2017**	**Yes**	**Yes**	**Yes**

9. Recognized International Conference(s) In Which Paper(s) Related To This Research Project Was / Were Delivered
(Please attach a copy of each conference abstract)

Month / Year / Place	Title	Conference Name	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this Report *(Yes or No)*	Acknowledged the Support of RGC *(Yes or No)*	Accessible from the Institutional Repository *(Yes or No)*
NA	NA	NA	NA	NA	NA	NA

10. Whether Research Experience And New Knowledge Has Been Transferred / Has Contributed To Teaching And Learning
(Please elaborate)

The proposed algorithm can be used as examples in some courses related to data mining and machine learning.

11. Student(s) Trained

(Please attach a copy of the title page of the thesis)

Name	Degree Registered for	Date of Registration	Date of Thesis Submission / Graduation
NA	NA	NA	NA

12. Other Impact

(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, teaching enhancement, etc.)

NA

13. Statistics on Research Outputs

	Peer-reviewed Journal Publications	Conference Papers	Scholarly Books, Monographs and Chapters	Patents Awarded	Other Research Outputs (please specify)	
No. of outputs arising directly from this research project	2	0	0	0	Type	No.
					NA	NA

14. Public Access Of Completion Report

(Please specify the information, if any, that cannot be provided for public access and give the reasons.)

Information that Cannot Be Provided for Public Access	Reasons
NA	NA