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Assoc Prof Vun Chan Hua, Nicholas, SCE (Supervisor)

Through: Chair, SCE

Thesis Examination – 1st Amendment Required
Ph.D. (SCE) - Le Thanh Hai G0802831E

The thesis submitted by the above student has been examined.

The student is required to make **major** amendments and submit the following:

i. 1 ring bound copy of the amended thesis to you within **6 months** from the date of this letter. If the stipulated deadline is not adhered to, the student will be liable to pay the tuition fee.

ii. Formal reply to the examiners' queries. Details refer to http://www.ntu.edu.sg/Students/Graduate/AcademicServices/ThesisExamination(forresearch students)/Pages/FormattoReplytoExaminer.aspx

Thereafter, the amended thesis and the replies to the examiners are to be sent to our Graduate Studies Office for re-examination, by completing and complying to the guidelines as stipulated in the form G/308/06.

The following are enclosed herewith:

i. 3 set(s) of the examiner's report.

ii. 1 copy/copies of the thesis returned.

Koh Kian Heng
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Report of Examiner No: 1
☑ For supervisor / candidate
☐ For examiner's use

PhD Thesis Examiner's Report

Title: Scalar and Homoskedastic Models for SAR and POLSAR Data

Candidate: Thanh Hai Le

Synthetic-aperture radar (SAR) and Polarimetric SAR (POLSAR) are forms of radar which have many applications including remote sensing and mapping of the earth surfaces. However, the transmitted signal arrived at the SAR or the POLSAR are inevitably interfered by scattering components and as a result the received data become a stochastic process. Retrieving information from stochastic processes is a very challenging problem. These have motivated the candidate to research into the statistical models for the SAR and the POLSAR data. His research objectives and methodology are stated clearly in Chapter 1.

The candidate provides a comprehensive literature review on the current research work on SAR and POLSAR in Chapter 2, particularly in the areas of statistical modeling, data processing and filtering, and evaluation of speckle filters. Discussion on various measurements for SAR and POLSAR data are also provided in this chapter.

In Chapter 3, the candidate provides a detailed statistical analysis on SAR data. Statistical models are presented which illustrate how the scattering coefficient affects the SAR data distribution. In his studies, the candidate noted that the existing models do not consider spatial variation that gives rise to heteroskedasticity phenomena. He then shows that the heteroskedastic SAR data can be converted into a homodkedastic model in logarithmic domain.

In Chapter 4, the candidate develops several statistical models for the multi-dimensional and inter-correlated POLSAR data. Heteroskedastic discrimination measures and homoskedastic measures of distance have also been derived.

In Chapter 5, the candidate explored further into applications in which a single scalar representing the multi-dimensional and inter-correlated POLSAR data is observed. He also demonstrated how the Mean-Squared Error can be applied to evaluate SAR as well as POLSAR speckle filters.

Conclusions on the contributions of his research work were provided in Chapter 6. Limitations of his proposed models and suggestion on possible future work were also provided in this chapter.

Overall the thesis is well written, except for some typo errors as indicated on the thesis, and contains original work. The amount of research work done is sufficient at the PhD degree level. Its findings have been presented in three international conferences and two papers currently under reviewed for possible publication in IEEE journal. It is recommended that the thesis be accepted for the award of the degree, subject to the correction of errors as marked in the thesis. Some suggested amendments and comments are also indicated in the thesis.

Report of Examiner No: 2
☒ For supervisor / candidate
☐ For examiner's use

PART 1: RESEARCH QUALITY AND THESIS PRESENTATION

1. Establishment of the Research Motivation and Objectives

This work aims to develop *homoskedastic* models for SAR and POLSAR data (which are heteroskedastic in nature), so that the benefits of conventional additive and homoskedastic statistical estimation framework can be applied.

Two main research objectives have been outlined in Sec 1.2, namely:

1. To derive scalar and representative statistical models for POLSAR data
2. To derive consistent measures of distance for both SAR and POLSAR data, which allow the use of the homoskedastic statistical estimation framework

SAR processing in the presence of multiplicative noise is a highly challenging topic. The research motivation and objectives are technically sound and suitable for PhD study.

Sec 1.1 and Sec 1.2 should be reviewed again in order to justify the significance of the research motivation, with proper citations on the background studies. There are many statements and arguable claims without explanations and references. In addition, Paragraph 1 of Sec 1.3.3 should be removed or rewritten. The achievements of research objectives should be stated in the conclusion chapter, with proper justifications based on experimental results and findings.

In the thesis (e.g. abstract, pg 8, 75, 129, 131, etc), it is mentioned that "a unified scalar statistical theory" has been proposed. This statement is questionable. Particularly, the use of the word "theory", which may require further justification, and more comprehensive and generalized explanations by providing solid proof or empirical support. I would suggest replacing the word "theory" with "model" throughout the thesis.

Secondly, it also appears several times in the thesis that "the proposal model is novel" (e.g. pg 8, 129, etc.). Novelty is a quality being new and original. In principle, the proposed model is derived based on the existing statistical models for SAR and extended to the POLSAR images. The use of MSE (mean square error) as the single unified evaluation criterion for SAR speckle filters is also arguable, as the proposed log-transform model will introduce an inevitable bias error, which may not be able to measure by MSE. In order to claim novelty, further clarifications of some key points (refer to Part II of this report) have to be addressed and included in the thesis.

2. Depth of the Analysis and Extensiveness of Data Collected

The proposed models are mainly used for the reduction of SAR speckle noise. A more comprehensive review of the relevant SAR/POLSAR speckle filters (Sec. 2.2.3 and Sec 2.2.4) should be included. Please refer to reviews on SAR speckle filtering by Lee et. al. [19], Touzi [20], as well as the most recent tutorial review by Argenti [21]. In terms of the evaluation of the SAR speckle filters (Sec 2.2.5), a critical review on existing methods should also be provided. These may include the use of with-reference indexes [2], [11], [12], [9], [13], [14], and without-reference indexes [15]-[18].

In a typical SAR image, there are at least three statistical classes can be observed: homogeneous, textured, and strong (or persistent) scatterer. A good speckle filter should be unbiased, able to smooth homogeneous areas (speckle noise reduction) while preserving textured areas (texture preservation) and point scatterers (radiometric preservation). Wherever possible, samples of SAR/POLSAR images with these three types of features should be used to evaluate the effectiveness of the proposed models.

3. Significance of the Thesis' Original Contributions

In my opinion, the derivation of the scalar statistical model for POLSAR data is the main contribution of the thesis. The log-transform is applied to polarimetric data and a discrimination measure of distance for POLSAR is derived. Compared to other models, the proposed models are highly representative of the multi-dimensional POLSAR data. It is also shown that the statistical model for SAR is a special case of the proposed model for POLSAR. The work done has great potential to be published in high impact factor journals such as *IEEE Journal on Selected Topics in Applied Earth Observations and Remote Sensing, International Journal of Remote Sensing, and Progress in Electromagnetics Research*.

4. Comprehensiveness of the Relevant References

There are many statements quoted without proper references. Particularly, in Chapter 1, which is the introduction chapter for readers, more relevant references should be provided so that readers can easily understand the background of the research. In addition, when a term is first used, it has to be clearly defined or cited. Some of them are highlighted below:

Page 2-3, (Research Motivation)

"... *POLSAR data is multi-dimensional, stochastic, multiplicative and heteroskedastic.*" – Define the terms: *heteroskedastic* and *homoskedastic* in the context of SAR imagery, with proper references.

"... *for example speckle filtering, target detection, image segmentation, and other clustering, classification techniques.*" – add references to this statement.

"... *most of these data processing techniques are traditionally design for additive and homoskedastic data.*" – add references.

"*Such use, however, is known to be not very robust for these so-called heavy tailed distributions.*" – any reference to support this statement?

"..*it is known that such use should be avoided in preference to a ratio-based discrimination measure.*" – add references.

"...*the Ordinary Least Square (OLS) is widely used as the best evaluation criteria which is probably due to the Gauss Markov theorem.*" – any reference to support this statement?

"..*violates the homoskedastic assumption of the theorem and thus many different ways to evaluate SAR speckle filters were proposed.*" – add references.

Define MSE when it is first used.

The term *scalar*, which is a keyword in the thesis title, is not mentioned in Sec 1.1. It has to be defined as well.

Similarly, in Sec 1.2, Sec 1.3, Sec 1.4, there are many statements without proper citations.

Thorough check is required to ensure all claims are supported by facts.

5. Other Comments

Not all the equations are numbered. It would be easier to read and refer if *all* the equations are labelled accordingly.

Some typographical changes are suggested in the Errata Sheet.

Errata Sheet

Page No.	Line No.	Comments/Errors	Suggestions/Should read as
Abstract-Table of Contents		There is no numbering for the first few pages (i-iv). Page (ii) is printed twice.	To include page numbering (i-iv)
1	13	single SAR channel	single-channel SAR
3	12	Similarly speaking,	Similarly,
	19	criteria	criterion,
4	14	MMSE criteria	MMSE criterion Define the term when it is first used.
6	9	Last but certainly not least,	Thirdly,
		such a framework allow	such a framework allows
9	7	multidimensional	Multi-dimensional
10	12	The model os	The model is
11	28	chapter 5	Chapter 5
12	6	chapter 6	Chapter 6
18	15	concenpt	concept
22	15	RadarSat	RadarSat-2 (RadarSat-1 is not a POLSAR)
24	14	SVM technique	Define SVM.
35	6-7	Rician distribution [48]...	And Rician distribution [48].
	11	back scattering	backscattering
36	10	literatured	literatures
37	2nd last line	Proposed bu	proposed by
39	4	dependence	dependency
44	Last line	The nature of SAR speckle is ...heteroskedastic heterogeneously.	Rephrase this sentense
46	4	most known common	most commonly known
56	6	POLSAR And	POLSAR. And

65	5,7	an homogeneous area	a homogeneous area
77	3	the objective then is	the objective is
	5-6	It has already been proven...	Which page or equations are you referring to? Provide a reference to the source.
87	Last line	Fig. 5.6a.	Fig. 5.6.
89		Figure 5.6 – subtitle: (a)	Remove the caption "(a)"
91		Figure 5.8	Legends are too small to read. Suggest to enlarge them.
95		Figure 5.12	Use the same scale for y-axis (i.e. MSE: 0:1) across all the plots.
103	22	related to the ENL index. over	related to the ENL index over
104	13	Equation 5.3.2.1	Incorrect numbering of equation
109	8	Figs. 5.21c and 5.21d allows	Fig 5.21(a) and Fig 5.21(d) allow
112	13	these smaller requirements	these requirements
132	9	evaluation criteria	evaluation criterion

Report of Examiner No: 3
☑ For supervisor / candidate
☐ For examiner's use

Name of Ph.D. Candidate: Le Thanh Hai

Title of Thesis: Scalar and Homoskedastic Models for SAR & POLSAR Data

Part I

This Doctor of Philosophy dissertation proposes several scalar statistical models based on the determinant of the POLSAR covariance matrix. Subsequently, logarithmic transformation is applied onto both SAR and POLSAR models to convert them into additive and homoskedastic models. The benefits of these models include the adaptation of many existing SAR data processing techniques for POLSAR data. Overall, this thesis has demonstrated novel contributions for the advancement in this research field. I have the following comments and suggestions in the order of the chapters of the thesis:

1. Overall Organization and presentation

   This thesis has six chapters, where the author introduces the research topic in chapter 1, gives a literature review in chapter 2, discusses the proposed models in chapters 3 and 4, describes some applications in chapter 5, and then concludes the thesis in chapter 6. The overall organization of the thesis is appropriate.

   However, the presentation needs to be considerably improved. For example, chapters 3 and 4 talk about "models" (plural – with an 's') but these models were not organized into sections with appropriate headings. In fact, the sections seem to be discussing various issues in developing the same model rather than different models (see my comments in the respective chapter below).

   In addition, some formatting issues have gone seriously wrong:

   Page ii of Contents page is missing.
   Page v: Usually, a Glossary is put at the end of a document.
   Why are some page numbers (ii, iii, iv, vi, viii, ix, xi) missing?
   Page xiii: List of source codes. These are actually pseudocodes and not source codes. Usually, we do not append source codes to a thesis.

2. Abstract

   Paragraph 3, line 1: "...several scalar statistical models ....". Since these models are the key contributions of the thesis, it would be good to give a separate name to each of these models so that it is clearer to the reader what they are and how many of them. Also, a short description of what each of them is suitable for should also be included in the abstract.

   The abstract lists the benefits of these models but not the shortcomings. Why? In an abstract,

the purpose is to give the reader a very quick summary of your thesis, including significant results and the potential value of your work. If you give vague descriptions of your contributions, the readers may think that your thesis is not worth reading and might skip your work and move on to someone else's work.

3. Chapter 1

Page 8: Table caption usually appears at the top of a table rather than below it.

No references throughout this chapter. Why? e.g. Page 3, last line of the first paragraph, "Such uses, however, is known to be not very robust for these so-called heavy-tailed distributions." Who made this claim? How reliable is this claim? Did the authors conduct a systematic evaluation of this claim?

Page 3, line 1: "Both SAR and POLSAR data however are multiplicative and heteroskedastic by nature". Firstly, you need a reference to this. Secondly, in your research, you are trying to propose an additive and homoskedastic model for the data. What makes you think that this model is appropriate? Just because there are a large number of algorithms in the field of computational intelligence that are linear and additive in nature, it doesn't mean that by fitting a homoskedastic model to heteroskedastic data, these algorithms will give you correct results. Please explain using references to related work why you think this approach is appropriate.

In section 1.4 "Research Contributions" it may be worthwhile to mention that the author's contributions had been published in various venues, together with a list of the author's publications arising from this work. I cannot find a list of the author's publications until I reach the conclusion of the thesis.

4. Chapter 2

This chapter is supposed to be a literature review chapter (from the title "Current methods in SAR and POLSAR Data Processing") but it also gives a description of the theory of the nature of the data (Section 2.1 "The stochastic and multivariate nature of (POL)SAR data"). However, this chapter is a little too heavy on the theory and not quite enough material on the related works.

What I mean is, in Section 2.1, the description of the theory on the nature of the data takes up 14 pages (page 13 to 27), while the entire chapter 2 is only 29 pages (page 13 to 42). This is about half of the entire chapter on literature review. Perhaps this theory section can be moved to a separate chapter so that more space can be dedicated to the discussion of related works.

Also, in section 2.2.3, on page 35, there is a list of "Other approaches that have recently been actively pursued in the research community" but there is no description of the techniques in

each class. If these classes of techniques are "recent" and "actively pursued", then there must be some value in them. The author should at least give a short description of each class of technique, the advantages and/or disadvantage in them as compared to the approaches you have described in the front part of section 2.2.3.

5. Chapter 3

The term "heteroskedastic" means that there are sub-populations that have different variabilities from others. So how can the statement on page 44, line 1, "... intensity are equal to a scaled version of these unit variables, specifically $A = \sigma A_1$ and $I = \sigma^2 I_1$" be true? The parameter σ cannot be a constant and it must be a function of either the position in (x, y) coordinates, or the amplitude A, or the Intensity I, or some other function that is yet to be determined. On page 44, paragraph 2, line 5, the author also mentioned that "However, over heterogeneous areas where σ varies signficantly, it is evident that .....". This means that the author is also aware that the σ cannot be a constant within a set of data.

If σ is not a constant, then the variance var(L_A) and var(L_I) shown in table 3.3 cannot be independent of σ , i.e. it cannot be homoskedastic. The author should provide some explanations of why he thinks that homoskedasticity is valid and what are the assumptions he may have made in this analysis.

Another point, both the abstract (paragraph 3) and the Chapter title suggests "various" models but I cannot see the different models that the author claims to have proposed. For example, if we look at the individual section headings in this chapter:

3.1 Original Heteroskedastic Model of SAR data
3.2 The Effects of Heteroskedasticity in SAR Processing
3.3 The Homoskedastic Effect of Logarithmic Transformation
3.4 Consistent Measures of Distance in the Log-Transformed Domain

they all seem to point towards the development of ONE model – the base-2 log-transformation of the SAR data. If there are different models, the author should give a name to each of his models (and put them into different sections) so that it is clear to the reader what are the models that have been proposed.

6. Chapter 4

Your approach applies the homoskedastic log transformation on the determinant of the POLSAR covariance matrix. When you have highly correlated data (i.e. homogeneous areas), the determinant $|\Sigma|$ will be very small, leading to a very narrow PDF (equation 4.1). Also, the inverse Σ^{-1} will be ill-defined, leading to large errors in your model. Please justify in what situations (if any) your model will not work well.

On page 66, 3rd paragraph, last sentence, the author declares that "A visual match is clearly observable which verifies the applicability of the theoretical models for the dispersion and contrast measures of distance.". However, In Fig 4.2(a) and (c), the simulated dispersion response has a peak that is much higher than the data at the same x-axis value of the polarimetric AIRSAR Flevoland data. In fact, it is much higher than **any** of the data in the dataset. This error could potentially be a very serious error as it may cause a wrong decision to be made (e.g. a threshold is set in the theoretical model which will never be reached by the real data, or unnecessary resources are provisioned to cope with a level of response that was never reached).

In fact, at that x-axis value, the real data has a value that is a sharp dip from its neighbouring values. Perhaps it is important to explain why the real data behaves in such a way? Does this imply that your choice of the stochastic model is not correct?

The section heading of 4.5.3 should be "Effective Number-of-Looks" instead of "Effect Number-of-Looks".

In the same way as Chapter 3, the chapter title mentioned "models" but the section headings point towards the development of only ONE model. Please make the necessary changes to correctly reflect the content.

7. Chapter 5

Page 94, section 5.2.2.2. MSE is first used here. What is MSE? Is it Mean-squared error? If yes, what is the reference value for calculating the MSE?

Fig 5.11 shows two curves that are almost, if not exactly, the same. One of them is "simulated result" and the other is "analysis formula". What is the difference between them? Isn't your simulation based on your analysis formula? If not please explain how your simulation is conducted.

Fig 5.12 shows the MSE criteria and speckle suppression power of your f-MLE filters for homogeneous areas. How does it compare with other state-of-the-art speckle filters (e.g. those listed in reference [83])?

Fig 5.13 Please label the two curves in your diagram!

In Fig 5.15 you show a comparison between the f-MLE filter and the boxcar filter for heterogeneous patterns. As you have pointed out that the boxcar filter is a simple filter (page 96 line 3), I am still curious about how the f-MLE filter will compare with other state-of-the-art filters for heterogeneous areas as well. Please show some such comparisons.

Looking at Fig 5.13 again, Fig 5.13 shows the result of "applying the 3 x 3 boxcar filter to two different homogeneous and SLC noise corrupted scenes" (page 96 line 3). Can I assume that (b) and (d) are the results of the boxcar filter for homogeneous area? Can these results be compared to the f-MLE results for homogeneous areas in Fig 5.12?

8. Chapter 6

In my opinion, the conclusion is the most badly written chapter in the whole thesis.

A conclusion is a place to summarize the main ideas of the thesis, and also to reinforce the values of the contributions and to **persuade** the user to believe in the proposed technique, and ultimately, to use them.

Page 131, 2nd paragraph. "It should be noted that the models are far from complete." If your models are far from complete, how can it be an accurate representation of the data?

Page 133, section 6.2.2, line 3: "...it is definitely not fully representative of the data". So, what kinds of error will it cause? How will it affect the use of your model? It is necessary to point out what are the shortcomings and how it will affect the use of your model.

Page 133, section 6.3, line 1 : "...its potential still mostly stays undiscovered". So what have you been doing in your thesis? Do 10% of the work and leave the other 90% for other people to do for you? A thesis is supposed to persuade others to believe what you have proposed and to use it. How can you expect others to believe in you when you yourself don't know most of what it is supposed to do?

On page 10, Chapter 1, the author specified a list of the "results to be obtained". However, in the conclusion chapter, there is no corresponding list of achievements to show that the objectives have been met.

9. Appendix

It is not usual to attached copies of academic papers in the Appendix. Moreover, the two papers that has a header of "IEEE Journal on Selected Topics in Applied Earth Observation and Remote Sensing" do not have a "Manuscript Received" date, which means that these papers are not yet submitted to the journal for review.

Two other papers ("SLC SAR Speckle filtering" and "FMLE SAR Speckle filtering") also do not have any venue nor typesetting information, which raises considerable doubts whether these papers were even submitted at all.

The thesis requires major revision based on the above comments. The student should correct grammatical and typographical mistakes made in this version and avoid making similar mistakes in the revised version. In summary, this thesis demonstrates extensive work of the candidate's research, and has shown novel contributions. It is self-contained and generally well-presented. The candidate has conducted focused and in-depth research, and has shown that he can perform quality research, and is encouraged to continue his research and publish his results in top venues.