Opponent's review of a doctoral thesis

Title in Czech: Modelování prostorově variantních optických systémů

Title in English: Modeling of Space Variant Optical Systems

Author: Ing. Petr Janout

Study programe: (P2612) Elektrotechnika a informatika/Electrical Engineering and Informatics

Study specialization: (2601V010) Radioelektronika/Radioelectronics

University: Czech Technical University in Prague, Faculty of Electrical Engineering

Introduction

When examining the dissertation, I proceeded from the facts presented in the doctoral thesis, the self-report, the journals and conference proceedings papers and in all aspects below.

The doctoral thesis is well and clearly presented in English, the thesis is logically divided into six parts within 103 pages, covering the theoretical part and the proposal of a model. Chapter 1 introduces known contributions to the design and the description of an optical system. Chapter 2 introduces the SVPSF imaging systems. Chapter 4 presents the necessary steps of the field dependency of polynomials in detail, and also the accuracy of the model. Verification of the proposed model is presented in Chapter 5. The model is subjected to a quantitative analysis, which demonstrates the versatility of the approach. The coefficients of the model are estimated for different cameras and for the optical model simulated in Zemax OpticStudio.

a) Topicality of the selected task

The problem presented within the doctoral thesis titled "Modeling of Space Variant Optical Systems" can be considered as current and currently being developed mainly in connection with applications as deconvolution, further processing and precise measurements (astrometry, photometry) of ultra-widefield images. The doctoral thesis topic is based on the three major works, by Weddell, Piotrowski, and Zheng as well and has very closed relationship to the relevant International projects and specific imaging systems as the Meteor Automatic Imager and Analyzer (MAIA) and the Thermal Hyperspectral Imaging System (THETIS). The monitored research is currently at the forefront of interest and research by different world laboratories, and European projects are also being addressed in this area. The chosen subject of work is clearly up to date.

b) Doctoral thesis aims and their fulfillment

Within the doctoral thesis there have been determined four relevant aims and these ones were fulfilled by the following way.

The PSF model describing the field-dependent PSF over the entire FOV, especially for UWFOV imaging systems, was proposed. The model extends current PSF models by expressing the field dependency of the PSF, and it allows a description of distorted off-axis PSFs with the desired accuracy. This description allows parts of the FOV to be processed that were formerly problematic or impossible to process.

The optical techniques for describing general imaging systems, such as the Zernike polynomials for describing the wavefront, were adapted.

The proposed model was verified and quantitatively analyzed on a series of image data acquired by SVPSF and UWFOV imaging systems, e.g. the WIde-field aLL-sky Image Analyzing Monitoring system (WILLIAM).

Confrontation of the verification results of the PSF model estimation with the results obtained by competing models was performed.

c) Selected methods within the doctoral thesis

The doctoral thesis contents the obvious methods used within the doctoral research. There is very well processed state of the art. Based on this state of the art there were formulated aims of the doctoral thesis. Theoretical research was then very important for the proposal of a model. Modeling of Space Variant Optical Systems focuses on methods for describing imaging systems. The model is based on the implementation of Zernike polynomials and their field-dependent coefficients. The thesis presents the search for a model that can describe the UWFOV imaging system or generally a SVPSF system, for which the PSF has not been adequately described. The method proposed in this thesis is based on modeling the PSF of the system, and comparing it with real image data without requiring measurements of the wavefront aberrations. After that there was performed an application of the introduced SVPSF model on simulated data, experimental laboratory-acquired data and real all-sky image data acquired by the WILLIAM imaging system. The system was developed at the Department of Radioelectronics, Faculty of Electrical Engineering, Czech Technical University in Prague, with the participation of the author of this thesis the principal designer. The polynomial model was applied and successfully verified on image datasets acquired by G2-83001, ASI 1600MM-Cool, and Nikon D5100 cameras. The last image dataset was simulated in Zemax OpticStudio. The author has thus demonstrated that he is able to use these methods appropriately and effectivelly within the relevant research.

d) The outcomes of the doctoral thesis

The novel PSF model with space-variant coefficients of the Zernike polynomials describing the field dependency of PSF was described in Chapter 4.

An algorithm for estimating the field-dependent coefficients was proposed, together with two evaluation methods.

A novel set of N-gon polynomials was introduced in Chapter 3. This chapter includes an analytic description and a performance analysis of the proposed polynomials.

The proposed model of the SVPSF was verified on a series of simulated laboratory acquired and real-sky image data. The results are faced with results obtained by other PSF estimation methods, and they demonstrate the suitability of the solution. Optimization of the coefficients was identified as a weak point of the model, due to difficulty with finding the global minimum of the function. An algorithm that helps to find a suitable set of coefficients was proposed.

The algorithm has been compared with other space-variant modeling methods. It has been shown to be competitive since the results are better than or equal to the results provided by other modeling methods. Other space-variant models provide accuracy around 8.5%. The results demonstrate that the approach described here is also suitable for UWFOV systems. The results compare models of imaging systems of 4th, 6th, and 8th orders of Zernike polynomials and show some benefits of using different orders. The accuracy of the results of different cameras varies from 3% to 10% in the central part of FOV and from 8% to 20% at the margin. The average precision of the model is below 10% precision. The contribution to the description of aberration is via a method for obtaining aberration coefficients in an unknown optical system and for using them in the model of space-variant PSF. The algorithm was used to model the WILLIAM system, and the model provided by the approach described here was used in a comparison of deconvolution methods.

There were developer SVPSF imaging systems as well. The systems were developed at the Department of Radioelectronics, Faculty of Electrical Engineering, Czech Technical University in Prague, with the participation of the author of this thesis. The author of this thesis has been involved in as a team member and in the case of the WILLIAM project, the author is the principal designer. In 2018, the THETIS project is in the phase of preparing a breadboard, and further activities will address the performance of the Calomel crystal in acousto-optic tunable filters.

e) Importance for practice or for further development of science

This thesis presents a PSF model with field-dependent polynomials. The model is based on Zernike polynomials up to the 8th order. An estimation of the parameters of the model was performed within the image plane, and this allows the imaging system to be modeled directly from the image data acquired by the systém instead of complicated measurements of optical parameters involving Shack-Hartman interferometry. The proposed model is used to provide a PSF model, including a set of coefficients and polynomials, and therefore provides the set and the power of the optical aberrations of the imaging system. The proposed PSF model has been verified on a series of simulated and acquired image datasets covering different types of imaging systems (CCD, CMOS) and optical designs/arrangements.

The thesis provides a workbench for modeling a complicated imaging system with SVPSF as well. Further work should address the influence of sensor grid sampling, and implementation of interpolation methods suitable for small objects. The model can be extended to different evaluation methods that meet specific requirements. Furthermore, the PSF model can be extended in a part of noise modeling. Implementation of mentioned techniques can improve the model for real scenes including a significant level of noise. The model introduced in the this doctoral thesis can be applied for the opposite purpose, i.e., as a simulator. It can be used for simulating PSF fields. A simulation of the PSF grid was used in thesis also. Using the simulator, the field of space-variant objects can, therefore, be simulated.

This thesis is an integral part of the doctoral study program "Electrical Engineering and Informatics", with its results the field develops, it brings new knowledge that can be used in the future. The positive aspect of the thesis is also the fact that the achieved results can be applied within the following research and within the educational process at all university levels as well.

f) General overall description

References

The whole number of references, i.e. 98, was used. Wide shot of publications years 1931 – 2018, especially then 2000 – 2018 (the majority of used references), sufficient number, app. 100, and representative selection of references were used. Relevant books, journals, proceedings and others categories were used. Within the WoS and SCOPUS, there can be found a few citations of the selected author´s papers.

Relevant scientific projects

There could be appreciated that the dissertation has contributed to several scientific projects also. This thesis has been partially supported by grants GA14-25251S: "Nonlinear imaging systems with spatially variant point spread function", GA17-05840S: "Multicriteria Optimization of Shift-Variant Imaging Systems", SGS13/212/OHK3 /3T/13: "Advanced Algorithms for Processing and Analysis of Scientific Image Data", SGS14/148/OHK3/2T/13: "Super-resolution microscopy imaging of mitochondrial networks", SGS16/165/OHK3/2T/13: "Algorithms for Advanced Modeling and Analysis of Optical Systems with Variable Impulse Response" and OHK3-027/18: "Analysis and advanced algorithms for ultra-wide imaging systems".

Author's publications

The outcome of the doctoral thesis were presented in at least in 16 papers. Two papers were published in journals with IF, one is under review. Three papers were published in reviewed journals. Seven papers were published in proceedings indexed in ISI (app. with extend from 8 to 13 pages). Four publications were included within the other groups including functional sample. There were used very good and relevant journals as Applied Sciences, Optics Express, Optical Engineering, Jemná mechanika a optika and conference proceeding as SPIE.

There shoud be appreciated that the extents of the following journal papers were 21 and 17 pages.

[A.1] Janout, P.; Páta, P.; Skala, P.; Bednář, J. *PSF Estimation of Space-Variant Ultra-Wide Field of View Imaging Systems*, In: Applied Sciences, 2017, 7(2). ISSN 2076-3417 – 21 pages, very well explained and illustrated, Figure 4. Diagram of the proposed algorithm.

[A.2] Páta, P.; Klíma, M.; Bednář, J.; Janout, P.; Barta, C.; Hasal, R.; Maresi, L.; Grabarnik, S. *OFT Sectorization Approach to Analysis of Optical Scattering in Mercurous Chloride Single Crystals*, In: Optics Express, 2015, 23(16), 21509-21526. ISSN 1094-4087 – 17 pages.

Formal layout of the dissertation thesis is well elaborated the linguistic level is good and all issues are well understandable. Formal and graphical style of this doctoral thesis is on a very high level. Figure 3.6 and Figure 4.1 are proof of this level (high quality and illustrative images)!

Formal shortcomings

Figure 2.4, the BEO abbreviation is not explained anywhere in the text nor in the Glossary on page xxi (apparently BEO means back-end-optics).

Chapter 4.2, page 46 - … in this paper is… could be replaced by the … in this thesis is…

Laroche-Prescott versus Laroche-Prescot has to be used by the same way in all cases.

A lot of references have incomplete record as regards relevant pages and DOI.

Reference [28] - source is uknown.

Reference [46] - it's patent, please see ISO 690, how to write citation.

Reference [59] - there is required relevant proceedings citation based on the link below
http://spie.org/Publications/Proceedings/Paper/10.1117/12.2274719 .

Reference [70] - incomplete citation.

Reference [95] - source is uknown.

It should be noted that these shortcomings are minor and they have no effect on the quality of doctoral thesis.

Possible questions:

1. Why there is the Bayer mask in high precision scientific systems with advanced Laroche-Prescott method of interpolation seems to be inappropriate solution? Because of on page 11 there is written that Laroche and Prescott´s interpolation represents a good compromise.

2. How did you ensure that the whole test scene is evenly lit when you take test shots? What causes a non-uniform illumination?

3. Does is necessary to use high order (e.g. 8^{th} order) Zernike polynomials in majority cases?

g) Conclusion

The presented doctoral thesis represents a complex processing of the selected problem. All parts required for doctoral thesis are included. The PhD student demonstrated the ability to work independently and orientation within the given topic.

The dissertation fulfills the conditions of a separate creative scientific work and contains the original and by the author of the dissertation published results of the scientific work in accordance with § 47, paragraph 4 of Act No. 111/1998 Coll., Article 28, paragraph 1 of the Study and Examination Rules for CTU students in Prague and Methodical Guideline No. 1/2009 "On the observance of ethical principles in the preparation of university graduate theses" issued by CTU Rector.

I recommend the dissertation for the defense.

doc. Ing. Jiří Hozman, Ph.D.
doctoral thesis opponent

doc. Ing. Jiří Hozman, Ph.D.
ČVUT v Praze/CTU in Prague
Fakulta biomedicínského inženýrství/Faculty of Biomedical Engineering
Katedra biomedicínské techniky/Department of Biomedical Technology
Nám. Sítná 3105
272 01 Kladno
Česká republika/Czech Republic
+420 728 335 738
hozman@fbmi.cvut.cz