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FACULTY OF
COMPUTER SCIENCE AND AUTOMATION

COMPUTER SCIENCE MEETS AUTOMATION

VOLUME II

Session 6 - Environmental Systems: Management and Optimisation

Session 7 - New Methods and Technologies for Medicine and Biology

Session 8 - Embedded System Design and Application

Session 9 - Image Processing, Image Analysis and Computer Vision

Session 10 - Mobile Communications

Session 11 - Education in Computer Science and Automation

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Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system's performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in "classical" technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title "Computer Science meets Automation", borne by the 52nd International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where "Computer Science meets Automation" are addressed by this colloquium at the Technische Universität Ilmenau.

All the University's Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.
I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.

Professor Peter Scharff
Rector, TU Ilmenau

Professor Christoph Ament
Head of Organisation

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52nd Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
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L. Hellrung / M. Trost

Automatic focus depending on an image processing algorithm for a non mydriatic fundus camera

ABSTRACT

This work presents an algorithm to focus a non mydriatic fundus camera automatically using an image processing approach to evaluate the actual state of an opto-mechanical focus aid. At present, the user has to adjust a focus and a positioning aid simultaneously. An automation of the focusing procedure would simplify the use of the device, especially for unpracticed users, and help to optimize the achievable image quality. A three-step algorithm is presented for detection of the interesting parts by adjustments of pattern matching, gradient search and blob analysis approaches. From image processing results a control sequence is generated for the focus motor of the camera device. The used methods were optimized and verified with a database of representative images. The efficiency and practical use of the implemented solution could be demonstrated by integration into the commercial fundus camera VISUCAM$^{PRO\ NM}$ by Carl Zeiss Meditec AG.

INTRODUCTION

The fundus of a human eye means the complete inner surface of the eyeball characterizing the retina, optic nerve and macula. In medicine, fundus imaging is used for the diagnosis of different diseases. According to the patient's eye, the quality of an image depends on the positioning and focusing accuracy of the fundus camera [2]. For non-mydriatic fundus imaging, i.e. undilated pupils, the fundus is illuminated with infrared light to avoid eye reactions. Due to the lack of contrast and structure, it's not possible to visually focus the system in this mode. Therefore, aids for positioning and focusing are projected onto the retina [3]. With the help of the two aids, the correct adjustment has to be found by user.

The principle task to focus the camera correctly can be seen from Fig. 2-1)). The two white focus bars have to be brought to alignment by changing the focus motor position manually.

Automation of the focusing procedure would simplify the handling of a fundus camera and help to optimize the achievable fundus image quality. A convenient automation approach has to deal with the tasks shown in Fig.1 in analogy to manual mode.

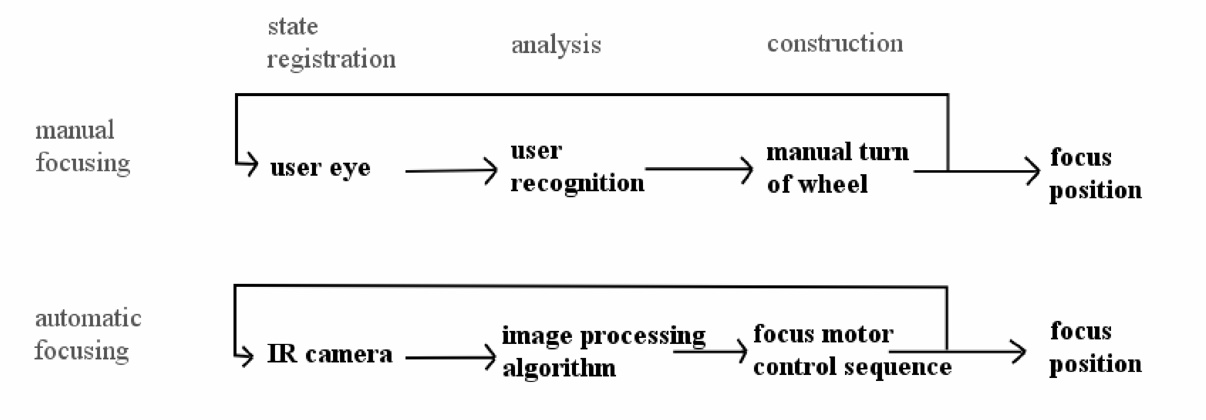

Fig. 1 Analogy of the tasks for manual and automatic focus procedure.

METHODS

For specifying the position of the focus bars a three-step detection algorithm was developed. For each step of the algorithm significant classification parameters are identified. Therewith, all intermediate results are classified by a Linear Discriminant Analysis (LDA). The first step is a pre-classification by histogram parameters. Pictures not containing the focus aid because of wrong positioning are ejected.

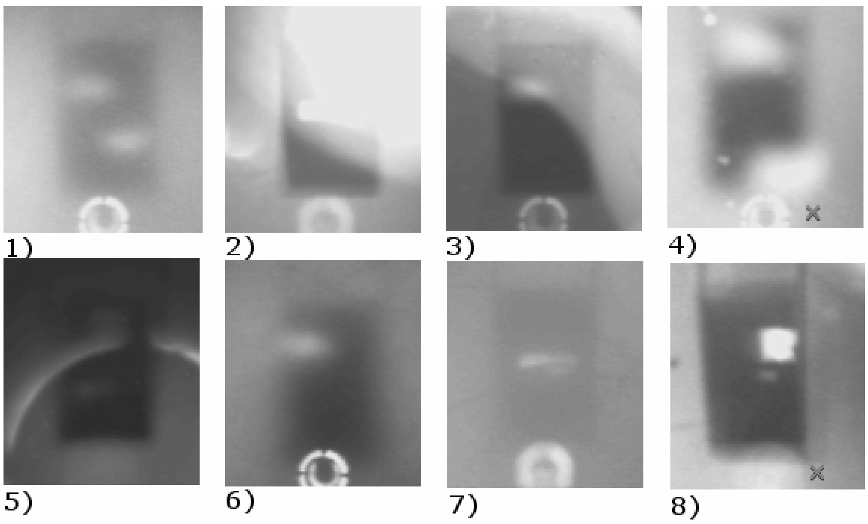

Fig. 2. Automatic evaluation of the IR images has to take different aspects into account. The principle task is to bring the two white focus bars to alignment (1). But the focus aid can be completely or nearly hidden (2,3) , deformed (8) or the edges can be hidden by the focus bars (4). Additionally, the focus bars are not always visible (3, 6), have different appearances (8), are strongly smeared (4,6) or hidden (5,7).

Second, the algorithm seeks for the darker rectangle of the focus aid background. The detection of the focus aid is complicated mostly by missing information about the position of the focus bars inside the focus aid and, additionally, by smearing effects and deformation with increasing ametropie of the eye (see Fig. 2-3),4),8)). The pattern matching uses a rectangular pattern with smoothed edges. For being invariant to focus bars positions, the normalized cross correlation is just calculated for the edge areas, leaving out the inner part of the pattern and the image part. Fig. 3 shows the principle rectangular pattern (1), the left out area when calculation correlation (2) and an exemplary correlation image (3).

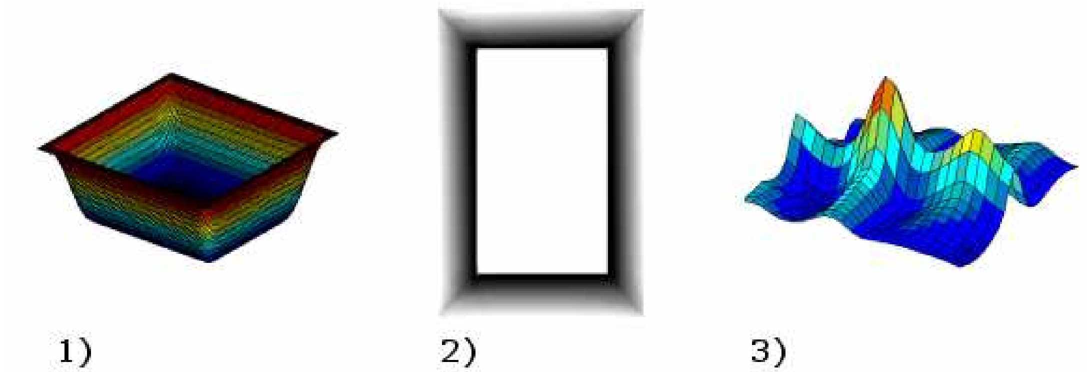

Fig. 3 Pattern matching approach with a smoothed rectangular pattern (1) for focus aid detection. For being invariant to the unknown position of the lightish focus bars inside, the normalized cross correlation is just calculated for the inner part (2). The result shows the correlation of the edge areas (3).

Additionally, a fast gradient search supports the decision of the pattern matching result. A gradient describes the neighbored grey value differences and can be minimal for light-dark crossing and maximal otherwise. That means, the horizontal (vertical) edges of the focus aid can be described ideally as minimum and maximum in the averaged gradient g(x) for all rows (columns). Additionally, an assumption about the approximated distance Δ of the edges can be made (see Fig. 4-1)). Due to the influence of the focus bars and other noise, it's not enough to detect the global minimum and maximum of g(x) (see Fig. 4-3)). Therefore, this gradient search detects similar extrema with the defined distance by the following. The signal g(x) is mirror-inverted, i.e. two similar maxima with distance Δ are expected. Then the signals g(x) and -g(x) are shifted about Δ and the minimum operator is used to remove all extrema with incorrect distance (see Fig. 4-2)). The resulting maximum of the curve describes the position of the edge pair. Finally, the inaccuracy of an approximated distance is cleared by searching the neighbored minimum and maximum of the averaged gradient.

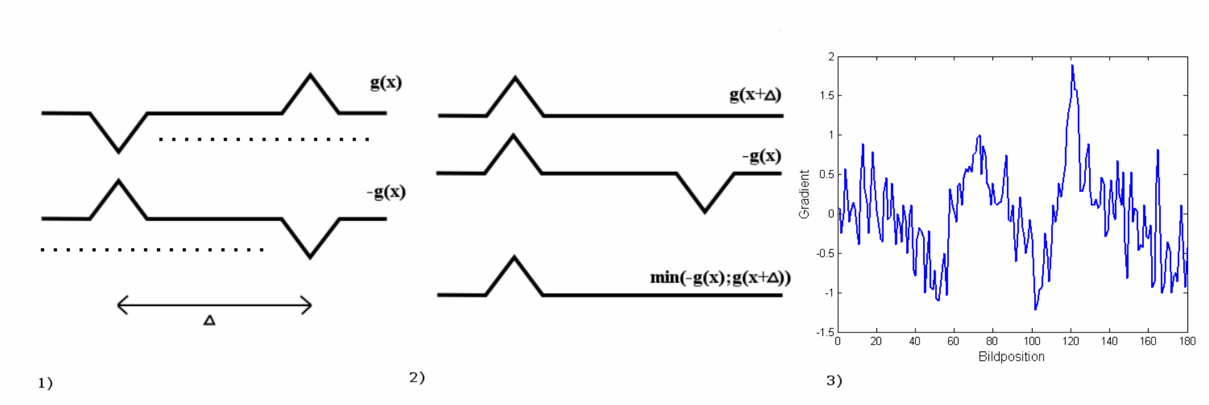

Fig.4. 1) The edge detection by gradient search is expecting ideally a minimum and maximum with distance Δ for the averaged gradient of image columns (rows). The inverted signal –g(x) is showing a similar maximum with distance Δ (pointed lines). 2) The signals g(x) and –g(x) are shifted about Δ. Using the minimum operator leads to significant maximum for the correct edge position. 3) This approach is necessary because of the influence by focus bars and noise to the real gradient signal.

The resulting rectangle of the focus aid search borders the Region-of-Interest for the third algorithm step, the detection of the focus bars. Following aspects have to be taken into account: different forms (see Fig.1-4), 7) and 8)), the unknown number of visible focus bars (see Fig. 1-6)) and interfering objects (Fig. 1-5)). A normalized cross correlation with a gaussian filter, see Fig.5-1), forces all approximately elliptical elements of the chosen filter size. The correlation image, see Fig. 5-2), is binarized whereas correlation peaks produce areas possibly being a focus bar, Fig.5-3). Parameters for the classification of the possible focus bars are calculated by blob analysis. From this, different form parameters are used for LDA –classification to identify the correct focus bars.

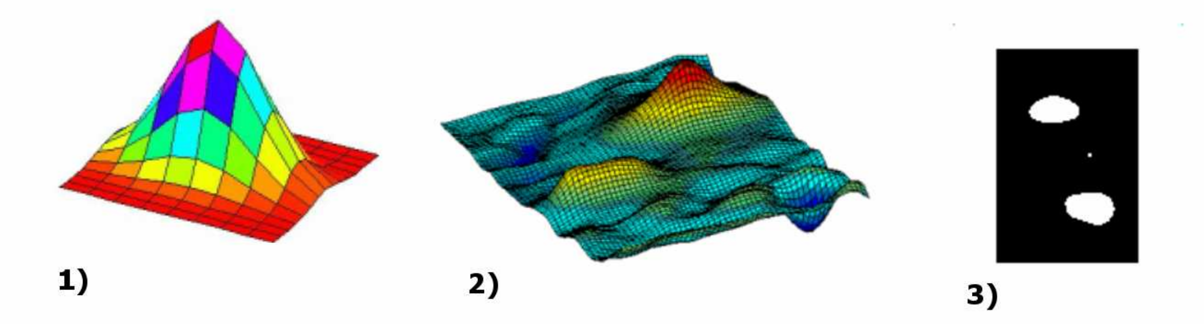

Fig. 5 Detection of the focus bars with normalized cross correlation with a Gaussian filter (1). The correlation image (2) is binarized and the resulting parts evaluated by blob analysis parameters (3).

If both focus bars could be detected, the positions are used to generate a control sequence for the focus motor. The new position is set and the resulting image is used for next control iteration until the focus bars are brought to alignment.

RESULTS

To avoid wrong control sequences for automation the reliability of the found focus bar positions is most important in establishing the objectives of the algorithm. The reason for this is given by the preferably not possible than wrong automation result. In this case, it means the minimization of false-positive detected focus bars. Therefore, more than 700 pictures from different patients, including an artifical lens and a cataract diseased eye, and an artificial eye with variable ametropie were taken. The pictures were evaluated manually und divided for training and validation data sets to identify significant parameters differing correct and incorrect detections used by Linear Discriminant Analysis. Also, used filter parameters, distances and the LDA coefficients were optimized.

The possible quality of the discrimination between correct and incorrect detections for each algorithm part is shown in Fig. 6. All figures show an adequate possible differentiation between the correct and incorrect detections. Most important is the high reliability of focus bar detections in part 3) to avoid false-positive detections of the focus bars not suffering from extremely high false-negative detection rate.

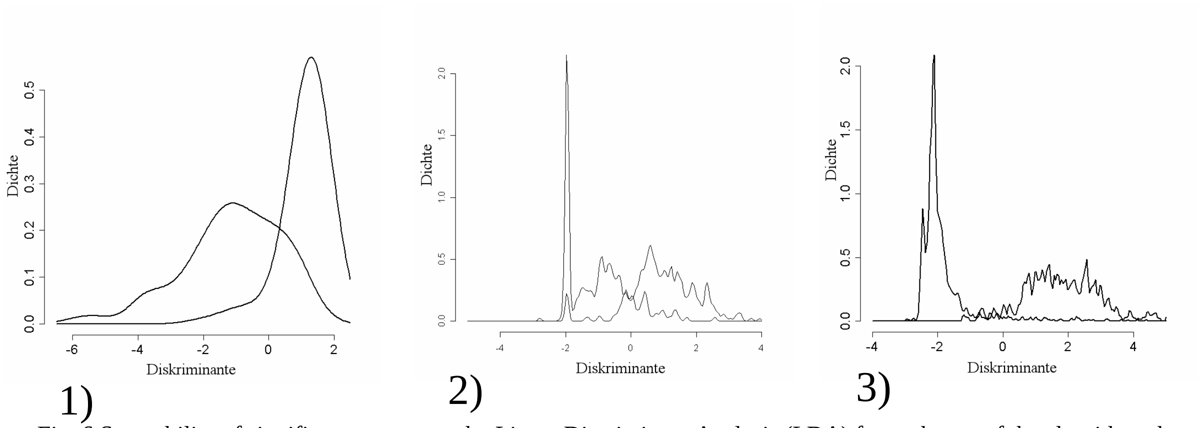

Fig. 6 Separability of significant parameters by Linear Discriminant Analysis (LDA) for each step of the algorithm, the pattern matching (1), gradient search (2) and focus bar detection by blob analysis parameters (3). Most important is the high discrimination of the real focus bars and detected noise.

After optimization, the entire algorithm leads to following results. The positive prediction value, meaning the correctness of a positive classification, is 95%. Additionally, the negative prediction value, meaning the correctness of a negative classification is 78,6%. Researches into the relation of focus bar distance and focus motor position addicted to a linear interrelationship to solve the generation of a control sequence.

DISCUSSION

An implementation of the presented algorithm is integrated into the existing device software for VISUCAM$^{PRO\ NM}$ by Carl Zeiss Meditec AG. It focuses a non mydriatic fundus camera automatically without any hardware changes of the system device. The image processing results shows that the detection of the focus aid by pattern matching is well separable into correct and false results. The reliability is increased by the gradient search. Due to the high separability of the focus bar detection, an adequate accuracy for practical use is possible. The promising theoretical positive and negative prediction values are supported by first clinical validations.

A linear equation describes sufficiently the interrelationship of focus bar distance and focus motor position for a fast and accurate control.

Problems of the algorithm arises from patients with strongly diseased eyes, e.g. by cataract and very small pupils. In this case, just one focus bar is reliably visible or the background of the focus aid is not cognizable anymore because of very strong smearing. Then, the proposed three-step algorithm cannot detect the focus bars.

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