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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

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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

Table of Contents

C O N T E N T S

Page

6 Environmental Systems: Management and Optimisation

T. Bernard, H. Linke, O. Krol 3
A Concept for the long term Optimization of regional Water Supply Systems as a Module of a Decision Support System

S. Röll, S. Hopfgarten, P. Li 11
A groundwater model for the area Darkhan in Kharaa river
Th. Bernard, H. Linke, O. Krol basin

A. Khatanbaatar Altantuul 17
The need designing integrated urban water management in cities of Mongolia

T. Rauschenbach, T. Pfützenreuter, Z. Tong 23
Model based water allocation decision support system for Beijing

T. Pfützenreuter, T. Rauschenbach 29
Surface Water Modelling with the Simulation Library ILM-River

D. Karimanzira, M. Jacobi 35
Modelling yearly residential water demand using neural networks

Th. Westerhoff, B. Scharaw 41
Model based management of the drinking water supply system of city Darkhan in Mongolia

N. Buyankhishig, N. Batsukh 47
Pumping well optimi ation in the Shivee-Ovoo coal mine Mongolia

S. Holzmüller-Laue, B. Göde, K. Rimane, N. Stoll 51
Data Management for Automated Life Science Applications

N. B. Chang, A. Gonzalez 57
A Decision Support System for Sensor Deployment in Water Distribution Systems for Improving the Infrastructure Safety

P. Hamolka, I. Vrublevsky, V. Parkoun, V. Sokol 63
New Film Temperature And Moisture Microsensors for Environmental Control Systems

N. Buyankhishig, M. Masumoto, M. Aley 67
Parameter estimation of an unconfined aquifer of the Tuul River basin Mongolia

M. Jacobi, D. Karimanzira 73
Demand Forecasting of Water Usage based on Kalman Filtering

7 New Methods and Technologies for Medicine and Biology

J. Meier, R. Bock, L. G. Nyúl, G. Michelson 81
Eye Fundus Image Processing System for Automated Glaucoma Classification

L. Hellrung, M. Trost 85
Automatic focus depending on an image processing algorithm for a
non mydriatic fundus camera

M. Hamsch, C. H. Igney, M. Vauhkonen 91
A Magnetic Induction Tomography System for Stroke Classification
and Diagnosis

T. Neumuth, A. Pretschner, O. Burgert 97
Surgical Workflow Monitoring with Generic Data Interfaces

M. Pfaff, D. Woetzel, D. Driesch, S. Toepfer, R. Huber, D. Pohlers, 103
D. Koczan, H.-J. Thiesen, R. Guthke, R. W. Kinne
Gene Expression Based Classification of Rheumatoid Arthritis and
Osteoarthritis Patients using Fuzzy Cluster and Rule Based Method

S. Toepfer, S. Zellmer, D. Driesch, D. Woetzel, R. Guthke, R. Gebhardt, M. Pfaff 107
A 2-Compartment Model of Glutamine and Ammonia Metabolism
in Liver Tissue

J. C. Ferreira, A. A. Fernandes, A. D. Santos 113
Modelling and Rapid Prototyping an Innovative Ankle-Foot Orthosis to
Correct Children Gait Pathology

H. T. Shandiz, E. Zahedi 119
Noninvasive Method in Diabetic Detection by Analyzing PPG Signals

S. V. Drobot, I. S. Asayenok, E. N. Zacepin, T. F. Sergiyenko, A. I. Svirnovskiy 123
Effects of Mm-Wave Electromagnetic Radiation on Sensitivity of
Human Lymphocytes to Ionizing Radiation and Chemical Agents in Vitro

8 Embedded System Design and Application

B. Däne 131
Modeling and Realization of DMA Based Serial Communication
for a Multi Processor System

M. Müller, A. Pacholik, W. Fengler 137
Tool Support for Formal System Verification

A. Pretschner, J. Alder, Ch. Meissner 143
A Contribution to the Design of Embedded Control Systems

R. Ubar, G. Jervan, J. Raik, M. Jenihhin, P. Ellervee 147
Dependability Evaluation in Fault Tolerant Systems with High-Level Decision Diagrams

A. Jutmann 153
On LFSR Polynomial Calculation for Test Time Reduction

M. Rosenberger, M. J. Schaub, S. C. N. Töpfer, G. Linß 159
Investigation of Efficient Strain Measurement at Smallest Areas Applying the Time to Digital (TDC) Principle

9 Image Processing, Image Analysis and Computer Vision

J. Meyer, R. Espiritu, J. Earthman 167
Virtual Bone Density Measurement for Dental Implants

F. Erfurth, W.-D. Schmidt, B. Nyuyki, A. Scheibe, P. Saluz, D. Faßler 173
Spectral Imaging Technology for Microarray Scanners

T. Langner, D. Kollhoff 179
Farbbasierte Druckbildinspektion an Rundkörpern

C. Lucht, F. Gaßmann, R. Jahn 185
Inline-Fehlerdetektion auf freigeformten, texturierten Oberflächen im Produktionsprozess

H.-W. Lahmann, M. Stöckmann 191
Optical Inspection of Cutting Tools by means of 2D- and 3D-Imaging Processing

A. Melitzki, G. Stanke, F. Weckend 197
Bestimmung von Raumpositionen durch Kombination von 2D-Bildverarbeitung und Mehrfachlinienlasertriangulation - am Beispiel von PKW-Stabilisatoren

F. Boochs, Ch. Raab, R. Schütze, J. Traiser, H. Wirth 203
3D contour detection by means of a multi camera system

M. Brandner 209
Vision-Based Surface Inspection of Aeronautic Parts using Active Stereo

H. Lettenbauer, D. Weiss 215
X-ray image acquisition, processing and evaluation for CT-based dimensional metrology

K. Sickel, V. Daum, J. Hornegger 221
Shortest Path Search with Constraints on Surface Models of In-the-ear Hearing Aids

S. Husung, G. Höhne, C. Weber 227
Efficient Use of Stereoscopic Projection for the Interactive Visualisation of Technical Products and Processes

N. Schuster 233
Measurement with subpixel-accuracy: Requirements and reality

P. Brückner, S. C. N. Töpfer, M. Correns, J. Schnee 239
Position- and colour-accurate probing of edges in colour images with subpixel resolution

E. Sparrer, T. Machleidt, R. Nestler, K.-H. Franke, M. Niebelschütz 245
Deconvolution of atomic force microscopy data in a special measurement mode – methods and practice

T. Machleidt, D. Kapusi, T. Langner, K.-H. Franke 251
Application of nonlinear equalization for characterizing AFM tip shape

D. Kapusi, T. Machleidt, R. Jahn, K.-H. Franke 257
Measuring large areas by white light interferometry at the nanopositioning and nanomeasuring machine (NPMM)

R. Burdick, T. Lorenz, K. Bobey 263
Characteristics of High Power LEDs and one example application in with-light-interferometry

T. Koch, K.-H. Franke 269
Aspekte der strukturbasierten Fusion multimodaler Satellitendaten und der Segmentierung fusionierter Bilder

T. Riedel, C. Thiel, C. Schmullius 275
A reliable and transferable classification approach towards operational land cover mapping combining optical and SAR data

B. Waske, V. Heinzel, M. Braun, G. Menz 281
Classification of SAR and Multispectral Imagery using Support Vector Machines

V. Heinzel, J. Franke, G. Menz 287
Assessment of differences in multisensoral remote sensing imageries caused by discrepancies in the relative spectral response functions

I. Aksit, K. Bünger, A. Fassbender, D. Frekers, Chr. Götze, J. Kemenas 293
An ultra-fast on-line microscopic optical quality assurance concept for small structures in an environment of man production

D. Hofmann, G. Linss 297
Application of Innovative Image Sensors for Quality Control

A. Jablonski, K. Kohrt, M. Böhm 303
Automatic quality grading of raw leather hides

M. Rosenberger, M. Schellhorn, P. Brückner, G. Linß 309
Uncompressed digital image data transfer for measurement techniques using a two wire signal line

R. Blaschek, B. Meffert 315
Feature point matching for stereo image processing using nonlinear filters

A. Mitsiukhin, V. Pachynin, E. Petrovskaya 321
Hartley Discrete Transform Image Coding

S. Hellbach, B. Lau, J. P. Eggert, E. Körner, H.-M. Groß 327
Multi-Cue Motion Segmentation

R. R. Alavi, K. Brieß 333
Image Processing Algorithms for Using a Moon Camera as Secondary Sensor for a Satellite Attitude Control System

S. Bauer, T. Döring, F. Meysel, R. Reulke 341
Traffic Surveillance using Video Image Detection Systems

M. A-Megeed Salem, B. Meffert 347
Wavelet-based Image Segmentation for Traffic Monitoring Systems

E. Einhorn, C. Schröter, H.-J. Böhme, H.-M. Groß 353
A Hybrid Kalman Filter Based Algorithm for Real-time Visual Obstacle Detection

U. Knauer, R. Stein, B. Meffert 359
Detection of opened honeybee brood cells at an early stage

10 Mobile Communications

K. Ghanem, N. Zamin-Khan, M. A. A. Kalil, A. Mitschele-Thiel — 367
Dynamic Reconfiguration for Distributing the Traffic Load in the Mobile Networks

N. Z.-Khan, M. A. A. Kalil, K. Ghanem, A. Mitschele-Thiel — 373
Generic Autonomic Architecture for Self-Management in Future Heterogeneous Networks

N. Z.-Khan, K. Ghanem, St. Leistritz, F. Liers, M. A. A. Kalil, H. Kärst, R. Böringer — 379
Network Management of Future Access Networks

St. Schmidt, H. Kärst, A. Mitschele-Thiel — 385
Towards cost-effective Area-wide Wi-Fi Provisioning

A. Yousef, M. A. A. Kalil — 391
A New Algorithm for an Efficient Stateful Address Autoconfiguration Protocol in Ad hoc Networks

M. A. A. Kalil, N. Zamin-Khan, H. Al-Mahdi, A. Mitschele-Thiel — 397
Evaluation and Improvement of Queueing Management Schemes in Multihop Ad hoc Networks

M. Ritzmann — 403
Scientific visualisation on mobile devices with limited resources

R. Brecht, A. Kraus, H. Krömker — 409
Entwicklung von Produktionsrichtlinien von Sport-Live-Berichterstattung für Mobile TV Übertragungen

N. A. Tam — 421
RCS-M: A Rate Control Scheme to Transport Multimedia Traffic over Satellite Links

Ch. Kellner, A. Mitschele-Thiel, A. Diab — 427
Performance Evaluation of MIFA, HMIP and HAWAII

A. Diab, A. Mitschele-Thiel — 433
MIFAv6: A Fast and Smooth Mobility Protocol for IPv6

A. Diab, A. Mitschele-Thiel — 439
CAMP: A New Tool to Analyse Mobility Management Protocols

11 Education in Computer Science and Automation

S. Bräunig, H.-U. Seidel 447
Learning Signal and Pattern Recognition with Virtual Instruments

St. Lambeck 453
Use of Rapid-Control-Prototyping Methods for the control of a nonlinear MIMO-System

R. Pittschellis 459
Automatisierungstechnische Ausbildung an Gymnasien

A. Diab, H.-D. Wuttke, K. Henke, A. Mitschele-Thiel, M. Ruhwedel 465
MAeLE: A Metadata-Driven Adaptive e-Learning Environment

V. Zöppig, O. Radler, M. Beier, T. Ströhla 471
Modular smart systems for motion control teaching

N. Pranke, K. Froitzheim 477
The Media Internet Streaming Toolbox

A. Fleischer, R. Andreev, Y. Pavlov, V. Terzieva 485
An Approach to Personalized Learning: A Technique of Estimation of Learners Preferences

N. Tsyrelchuk, E. Ruchaevskaia 491
Innovational pedagogical technologies and the Information educational medium in the training of the specialists

Ch. Noack, S. Schwintek, Ch. Ament 497
Design of a modular mechanical demonstration system for control engineering lectures

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P. Brückner/ S.C.N. Töpfer/ M. Correns/ J. Schnee

Position- and colour-accurate probing of edges in colour images with subpixel resolution

ABSTRACT

This paper presents a novel method for probing of edges in colour images with subpixel resolution. The enhanced method based on [1] enables the highly precise determination of the edge position at edges with a change in colour as well as with a change in intensity or a combination of both. The attained precision is similar to the precision of subpixel-accurate edge position determination in greyvalue images.

INTRODUCTION

Subpixeling methods enable probing of edges in greyvalue images with a resolution larger than the pixel centre distance of the sensors. Depending on the quality of the image data an increase of resolution of 1/10th to 1/100th pixels is attainable [2]. Typically, methods for subpixel-accurate edge position determination presume that only one function value, id est the intensity respectively the greyvalue, varies within the image. Colour images do not fulfil this requirement. They contain three function values, which may vary with the position within the image, for example the primary colours red R(x, y), green G(x, y) and blue B(x, y).

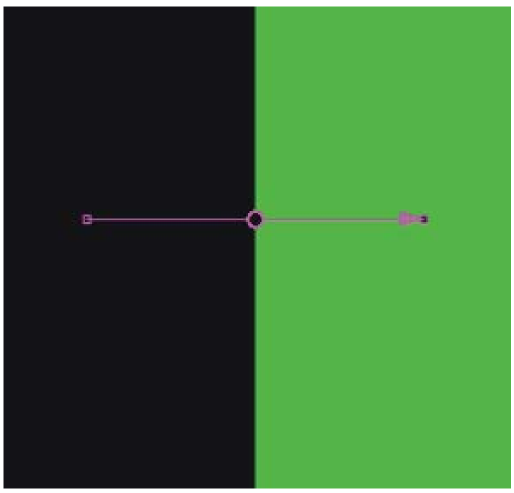

Fig. 1: Colour edge with search line

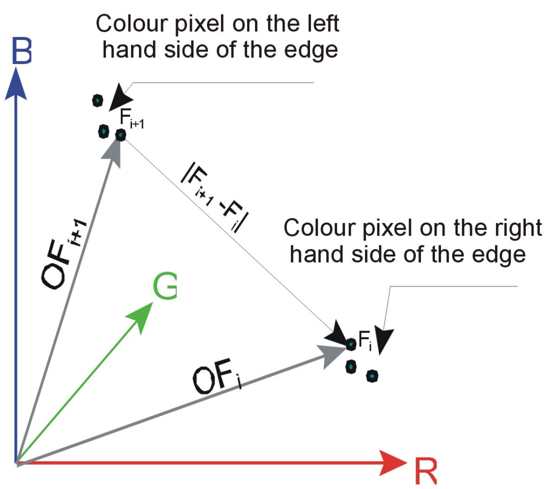

Fig. 2: Definition of the position vectors *OF*

The solution consists of a vectorial approach. Each pixel of the colour image is considered as a vector. Similar to measurements in greyvalue images a search line is defined (Fig. 1). The search line comprises RGB colour values, which can be represented as vectors in the RGB colour space (Fig. 2). Appropriate vector operations are deployed on each colour vector of two neighbouring pixels. Thus, a one-dimensional function scaled between 0 and 255 is derived for the whole search line. Thus, the edge position is determined by subpixeling as in greyvalue images.

STATE OF THE ART

The known deployed methods for edge detection in colour images yield the pixel-accurate position only. They are mainly utilised for image segmentation and object recognition. If edges are determined for the individual colour channels R, G and B, as in [3], or for only one colour channel as in [4], image information is lost. This applies also if colour images are converted into greyvalue images, as in [5]. A better method is shown in [6] and [7], which convert image data into the HSI colour space. This enables the detection of changes in hue and in intensity with varied Sobel operators. Vector based methods are showing the best performance for edge detection in colour images. They treat each pixel as a vector in a usually three dimensional colour space. The edge detection is done with a variety of operators. The works [8], [9], [10], [11], and [12] deal with the vector gradient operator. In [8] and especially in [9] vector order statistic operators and the entropy operator are examined. In [8], [11], [12] and [13] the difference vector operator or comparable distance metrics are used. Furthermore, operators based on the second derivatives are introduced in [8]. The variety of these operators for colour edge detection proves that no perfect colour edge detection operator exists. Consequently, there are different colour edge detection operators most suitable for each specific task [8]. Basically, the aim of this paper is not edge detection but the highly precise edge position determination. Only few papers are dealing with this issue, for example [14] and [1]. The paper at hand develops these ideas further.

In optical coordinate metrology well known subpixeling methods for probing of edges with subpixel resolution in greyvalue images exist. In [2] an overview of different methods such as threshold ~, differential ~ and integral methods (e.g. photometric mean) as well as correlation and parameter identification is given. Combined with interpolation, approximation and reconstruction subpixel resolution is attained.

The absolute value of the vector difference $|\vec{u}-\vec{v}|$ of the two three dimensional vectors $\vec{u}$ and $\vec{v}$ is calculated as:

$$\vec{u}=\begin{pmatrix}u_1\\u_2\\u_3\end{pmatrix},\quad \vec{v}=\begin{pmatrix}v_1\\v_2\\v_3\end{pmatrix},\quad |\vec{u}-\vec{v}|=\left|\begin{pmatrix}u_1 & - & v_1\\u_2 & - & v_2\\u_3 & - & v_3\end{pmatrix}\right|.$$

The conversion of the coloured search line into a function with one intensity value only is done via vector difference. Therefore, the absolute value of the vector differences of two adjacent colour vectors is calculated for the whole search line. The absolute value of the vector differences is maximal at the edge because of the changes in intensity and colour. Thus, the calculated one-dimensional function has low intensities at homogeneous areas and an intensity peak at the edge.

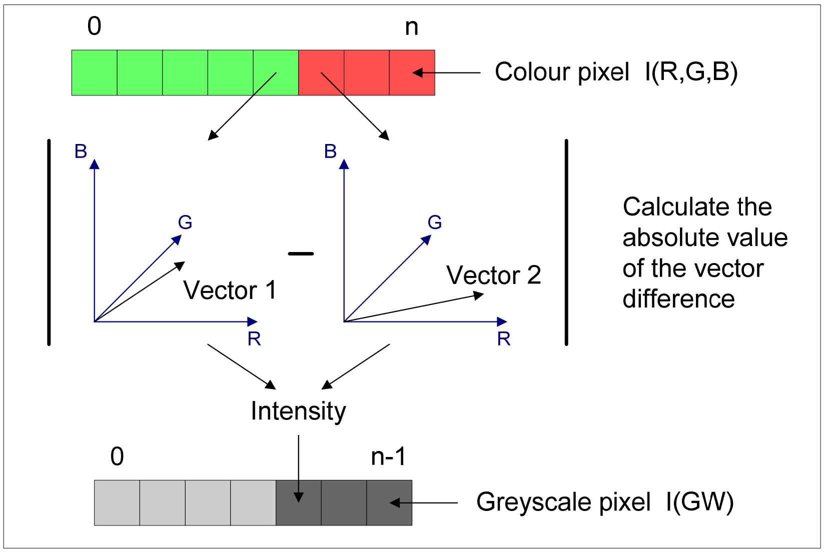

Fig. 3: Conversion of a search line through the vector difference

The edge position is at the centre of gravity of the intensity peak. Since the vector difference is calculated from two neighbouring vectors or pixels, n colour pixels yield only n-1 vector differences (Fig. 3). Consequently, the converted search line has one pixel less than the coloured original. This also entails a systematic shift of the calculated edge position by 0.5 pixels which has to be included. For the precise determination of the edge position with subpixel resolution the outlined methods from [2] are applied on the one-dimensional function. Due to the characteristic peak of the intensity function marking the edge position a correlation method has been chosen. It determines the maximum correlation between the intensity function and a Gaussian-shaped reference pattern. The subpixel-accurate edge position equals the centre of gravity of the calculated curve of the correlation coefficient. Finally, the mentioned 0.5 pixel shift is charged in order to determine the accurate edge position in the colour image.

SIMULATIONS

Several simulations have been performed. One simulation demonstrated that the vector operations cross product and dot product are not suitable for the conversion of the coloured search line. The cross product does not yield a change in its characteristics if the edge is represented by a pure intensity change (Fig. 4). The dot product is equally unsuitable for dimensional measurements. Depending on the absolute value of the change in the original intensity function in the colour image its signal flank marking the edge is shifted relative to the actual edge position.

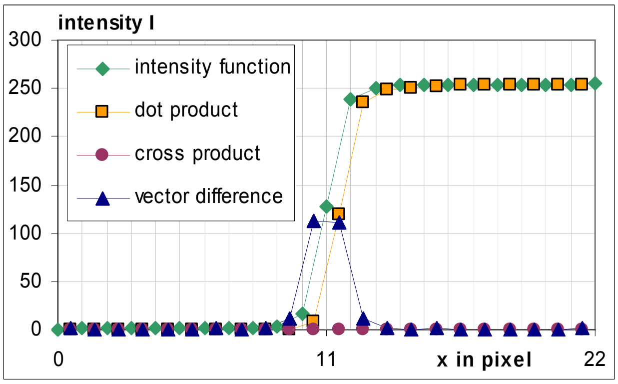

Fig. 4: Vector operations at an edge in a colour image (intensity function) with pure intensity change

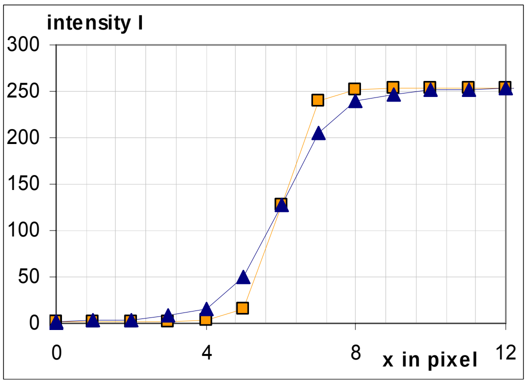

Fig. 5: Simulated intensity function for a thin (square) and for a broad edge (triangle)

An other set of simulations was performed in order to evaluate the performance of the outlined method for subpixel-accurate edge probing in colour images independently from the actual lens and the imaging sensor. Therefore artificially generated edges with known edge position were utilised (Fig. 5). The intensity functions have been saved as 8 bit greyvalue images and as 24 bit colour images where each colour channel contained the identical intensity function. The results from the greyvalue subpixeling and from the proposed colour subpixeling have been compared.

Table 1: Average deviation from the known edge position in pixels for 24 bit colour images and for 8 bit greyvalue images at different intensity functions with 8 search lines at 4 angles between 45° and 90° relative to the edge for both probing directions.

Deployed intensity function (see Fig. 5)	Deviation of edge position in greyvalue image	Deviation of edge position in colour image
Thin edge with int. transition 0 to 254	0,0122	0,0150
Thin edge with int. transition 30 to 200	0,0134	0,0165
Thin edge with int. transition 50 to 170	0,0096	0,0140
Broad edge with int. transition 0 to 254	0,0091	0,0126
Broad edge with int. transition 30 to 200	0,0055	0,0163
Broad edge with int. transition 50 to 170	0,0159	0,0201

The deviation of the determined edge position amounts to the same order of magnitude for greyvalue ~ and for colour subpixeling (Tab. 1). However, the results of the greyvalue subpixeling are slightly better. The attained subpixel resolution is approximately 1/100th pixel.

EXPERIMENTAL RESULTS

In order to determine the performance of colour subpixeling under real measuring conditions a circular calibration target has been captured with a colour and a greylevel camera. The latter was an ADIMEC MX12P/8X23 CCD camera with 1024 x 1024 pixels with a pixel size of 7,5 µm x 7,5 µm. The colour camera was a BASLER A113CP equipped with a Bayer filter mosaic with 1300 x 1030 pixels with a pixel size of 6,7 µm x 6,7 µm. For comparability both cameras where utilised with the same optical reproduction system (one fold magnification) and the same cold light source (colour temperature app. 5000 Kelvin) as transmitted light illumination.

As Table 2 shows, the experimental results validate the simulation results. The small differences between greyvalue ~ and colour subpixeling are due to the different cameras. The colour camera has a much larger noise and a reduced spatial resolution due to the Bayer filter mosaic. Therefore, the 7th and 8th column contain the measured values for greylevel subpixeling which has been deployed on the colour images after they have been converted into greylevel images based on the well known luminance equation. Thus, it is proven that the larger part of the deviation is in deed due to the camera characteristics and not due to the subpixeling method.

Table 1: Circle radii measured at the same calibration target and captured with greyvalue ~ and colour camera (average from 50 measurements, pixel factor calibrated at 5th circular ring, all values in µm)

Circular ring	Calibration value, radius [µm]	Measurement in greylevel image		Measurement in colour image			
				Original colour image		Converted into greyvalue image	
		Radius	Deviation	Radius	Deviation	Radius	Deviation
3	249,60	249,52	-0,08	249,37	-0,23	249,32	-0,28
4	500,39	500,35	-0,04	500,13	-0,26	500,08	-0,31
5	999,72	999,72	0,00	999,72	0,00	999,72	0,00
6	2000,40	2000,31	-0,09	2000,38	-0,02	2000,29	-0,11

The performed experiments prove the suitability of the proposed colour subpixeling for high-resolution dimensional measurements. Nevertheless, most decisive for the achievable accuracy is the quality of the image data as well as the characteristic of the actual measuring object, e.g. colour distribution.

SUMMARY

A method for the highly accurate determination of the edge position in colour images has been outlined. Key principle is the vectorial approach which allows the subsequent application of established subpixel methods for greylevel images. The originality of the paper lies with the detailed investigation of the applicability of the proposed methods for determining the edge position with subpixel accuracy. There are three basic types of edges in colour images. It must be differed between edges represented by a pure intensity transition and edges represented by a pure colour change and edges represented by any combination of the previous two edge types. The vector difference is the only method that enables the determination of the edge position with subpixel accuracy in colour images for all three edge types. Based on simulated and measured data it is demonstrated that a resolution of approximately 1/100th pixel can be attained. Prerequisite is the utilisation of a colour camera with low noise.

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