Application

2015-03-31

2015-04067	Gooran, Sasan	NT-14

Information about applicant

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Information about application

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Descriptive data

Project info

Project title (Swedish)*

Spatial-spektral bildreproduktion

Project title (English)*

Spatio-Spectral Image Reproduction

Abstract (English)*

Colour reproduction works basically because of the fact that we can produce a wide range of colours by mixing a few basic light spectra, using the so-called primaries of the device, e.g. the Red, Green and Blue phosphors used on a TV, or the Cyan, Magenta and Yellow inks used in colour printing. This usually leads to good reproductions under given conditions, but the quality may degrade drastically when viewed in slightly different circumstances.
Recently, multi-colorant printers with additional colorants to increase the range of reproducible colours have been introduced. We aim to use the available extra primaries to achieve a better approximation to the spectral properties of the original. Such an improved spectral reproduction will match an original closer under varying viewing conditions and for a wider range of observers, including persons with colour deficiencies.
There is also one important aspect of visual perception that is largely overlooked in conventional colour reproduction - the spatial aspect. Traditional models employ point-wise colour vision models, which very often fails to incorporate important aspects of human vision.
The project will develop models within two areas: 1) Conversion of the spectral input image into the colorants employed by the multi-colorant printer. 2) Quality evaluation, incorporating not only spectral properties, but also the complex relation of spatial properties and human colour perception.

Popular scientific description (Swedish)*

Den mänskliga uppfattningen av färg skapas genom signalerna från tre olika typer av ljuskänsliga tappar i ögat. All konventionell bildreproduktion är baserat på egenskaperna hos vårt färgseende, och utnyttjar det faktum att man med endast ett fåtal tillgängliga spektralfördelningar, s.k. primärfärger, kan skapa en mängd olika upplevda färgintryck. Till exempel så kan man på en TV-skärm skapa färgförnimmelsen av en röd stuga med de tre primärfärgerna rött grönt och blått som emitteras från färgens tre olika typer av fosfor, även om man omöjligt kan återskapa spektralfördelningen hos ljuset som reflekteras från husets röda vägg. Man måste alltså skilja mellan begreppet ”färg”, som en upplevd sinnesförnimmelse, och det fysiska stimulus som ger upphov till färgupplevelsen, nämligen det infallande ljusets spektralfördelning.

Om man vill reproducera en naturtrogen bild av ett konstverk kan man med dagens teknik i bästa fall producera en bild där de upplevda färgerna överensstämmer med originalet under mycket specifika förutsättningar. Då de spektrala egenskaperna skiljer sig från originalet måste man anpassa reproduktionen till att ge samma upplevda färgförnimmelse för en betraktare som har ”normalt” färgseende och förutsätta en belysning med en specifik spektralfördelning. Så snart egenskaperna för belysningen ändras, eller för en betraktare med ett färgseende som inte överensstämmer med den modell som används, kommer färgerna inte längre att överensstämma. Idag har nära 10 % av befolkningen någon form av defekt på färgseendet. Samtidigt introduceras allt fler nya typer av nya energibesparande ljuskällor, som alla har väsentligt olika ljusegenskaper jämfört med såväl varandra, som med traditionella ljuskällor, och med naturligt dagsljus. Att reproducera bilder med korrekta färger, istället för att endast återskapa en färgförnimmelse under specifika förhållanden, är alltså en omöjlighet med dagens konventionella bildreproduktion.

På samma sätt som man vid reproduktion av bilder använder sig av ett fåtal primärfärger, har man traditionellt använt sig av tre olika färgkanaler (RGB) för att representera färg i digitala bilder. På senare år har den snabba utvecklingen av processorkraft, tillsammans med tillgänglig och billig datalagring, öppnat upp för möjligheten till multispektrala bilder, där man använder betydligt fler än tre färgkanaler. Ofta används t.ex. 31 kanaler för att representera hela det synliga våglängdsområdet. Där en RGB-bild endast representerar en scen fångad med en specifik enhet (t.ex. en digitalkamera) under en specifik belysning, så representerar en multispektral bild de fysiska egenskaperna hos ett objekt eller en scen, oberoende av ljuskällan. Antalet databaser med multispektrala bilder ökar och i strävan att bevara konsthistoriskt viktiga föremål finns idag även multispektrala bilder av ett stort antal konstverk.

Även när det gäller system för färgreproduktion har utvecklingen gått mot att addera allt fler färgkanaler, och i dag finns t.ex. bläckstråleskrivare som använder upp till 12 färger tillgängliga på konsumentmarknaden. Anledningen att lägga till ytterligare färgkanaler har varit att man vill förbättra färgåtergivningen genom att utöka antalet färger som kan reproduceras, och för att få visuellt behagliga färgövergångar. Vi föreslår att man använder de extra färgkanalerna på ett helt annat sätt, med målet att inte bara reproducera bilder som visuellt ”ser bra ut”, utan istället använda tillgängliga färgkanaler till att efterlikna de spektrala egenskaperna hos ett original. Med en sådan spektral bildreproduktion skulle en reproducerad bild vara identisk med originalet, oavsett om den betraktas i dagsljus, i kontrollerad belysning på ett museum, under en modern LED-belysning, eller en traditionell glödlampa. Vidare skulle färgreproduktionen vara korrekt för alla betraktare, oavsett individuella avvikelser i färgseendet från den ”standardobservatör” som i dag används för att representera normalt färgseende.

Ytterligare en viktig begränsning hos konventionell färgreproduktion och befintliga mått på bildkvalitet, är att dessa fungerar punktvis, utan hänsyn till omgivningen. Då vår färgperception är ytterst komplex och till stor del påverkas av spatiala effekter, måste även dessa inkluderas. Vi föreslår därför att man utvecklar samtliga delar av bildreproduktionskedjan, genom att inkludera både spektrala egenskaper och spatiala effekter.

Project period

Number of project years*

3

Calculated project time*

2016-01-01 - 2018-12-31

Classifications

Select a minimum of one and a maximum of three SCB-codes in order of priority.

Select the SCB-code in three levels and then click the lower plus-button to save your selection.

SCB-codes* 2. Teknik > 211. Annan teknik > 21102. Mediateknik

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Enter a minimum of three, and up to five, short keywords that describe your project.

Keyword 1*

Spectral Image Reproduction

Keyword 2*

Multi-channel Printing

Keyword 3*

Spectral Color Separation

Keyword 4

Digital Halftoning

Keyword 5

Ethical considerations

Specify any ethical issues that the project (or equivalent) raises, and describe how they will be addressed in your research. Also indicate the specific considerations that might be relevant to your application.

Reporting of ethical considerations*

No ethical aspects in the project

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

Spatio-Spectral Image Reproduction

Purpose and aims

The perception and reproduction of audio- and spatial information follows two fundamentally different principles. We can hear the difference between the same sound produced by a flute and a fiddle, but we perceive the red colour of a house on a TV monitor as the same colour as that of the real house. If we want to produce a sound played by a flute we have to generate a sound wave that is similar to the sound wave produced by the flute. On the other hand, we can generate the perception of a colour without actually producing a particular spectrum of light. It is therefore important to differentiate between colour, the result of a perception, and the light spectrum that is the cause of this perception. Conventional colour reproduction is based on the fact that we can produce a wide range of colour perceptions by mixing a few basic light spectra, using the so-called *primaries* of the device, e.g. the Red, Green and Blue phosphors used on a TV, or the Cyan, Magenta and Yellow inks used in colour printing. This usually leads to good reproductions under given conditions, but the quality may degrade drastically under slightly different conditions.

Recently, multi-colorant printers that add additional colorants in order to increase the range of reproducible colours have been introduced. We aim to use the available extra primaries in a completely different way: to better approximate the spectral properties of an original, instead of merely its predicted colour perception under specific viewing conditions. A perfect spectral reproduction would match an original under any condition and for any observer, including persons with colour deficiencies.

Another drawback of conventional multi-channel reproductions is the absence of spatial considerations. Point-wise colour vision models very often fail, since spatial aspects are fundamental in the study of colour vision. The overall goal of the proposed research is therefore:

> ***To generalize conventional colour reproduction models by incorporating both spatial and spectral components.***

Spatio-Spectral Image Reproduction requires new methods to convert the spectral input image into the distribution of the colorants employed by the multi-colorant printer, in a way that takes into account the highly non-linear printing process. The evaluation of the quality of the reproduced images will require new models for quality assessment, incorporating not only spectral properties, but also the complex relation of spatial properties and human colour perception.

The research group combines experiences from research in colour science, halftoning, multispectral imaging, printer modelling and paper optics. The proposed research will benefit from sharing equipment and results from an on-going research project on multi-channel printing, but will provide new knowledge about the complete reproduction chain by developing models that include both spatial and spectral aspects.

Survey of the field

In colour reproduction, the intent is to reproduce the colours of an original as good as possible, within the constraints imposed by the technology. There are several ways to define what "good" means in this context, for instance one might want to aim for a reproduction that is pleasing in the eyes of a human observer, or a reproduction that is measured to be colorimetrically identical to the original. Since the human visual system uses three different types of photosensitive cells (the cones of the retina), it is possible to achieve good quality colour reproduction with technologies using three primaries (e.g. the red, green, and blue phosphors of displays). However, three-primary colour reproduction technologies suffer the important shortcoming that the reproduced colour depends heavily on the conditions under which it is viewed. For instance in cultural heritage, a museum curator might want to create faithful colour reproductions of paintings, using a high-end digital colour camera and a high quality inkjet printer on photographic paper. While such reproductions might appear almost perfectly equal to the original in laboratory lighting conditions, they will certainly appear different when viewed in daylight or in museum/gallery lighting. This issue can be well understood by the perceptual effect known as metamerism, which implies that two samples can appear to have exactly the same colour even though their spectral reflectances are significantly different.

In the field of multispectral imaging, technologies and methodologies have been developed which enables the acquisition of the spectral reflectance of a scene or object surface, using techniques such as rotating filter wheels or liquid crystal tuneable filters. With such technologies, the resulting images consist of a significantly higher number of channels (spectral bands). Typically 31 such channels (with 10nm spectral sampling) are used.

Recently, multi-colorant printers that include up to 12 different colorants have been introduced into the market. The main goal of this development has been to increase the range of reproducible colours, the so-called gamut of the printer. By using the available extra primaries in a completely different way, and by attempting to approximate the spectral reflectance of the original instead of merely its colour, significant improvements can be achieved. The availability of the technology described above, coupled with the dramatic increase in computational speed and data storage capacity, now enables considerable research advancements in the field of spectral colour reproduction. A successful spectral colour reproduction will match an original for any observer and under any illumination.

Spectral modelling / colorant separation

The spectral modelling of multi-colorant printers establishes the transform between the device control values (or colorant combinations) sent to the printer, and the resulting spectral reflectance. The forward printer model predicts the resulting spectral reflectance for a given set of colorant combinations while the inverse printer model gives the colorant combination required to produce a certain spectral reflectance, a process also known as colorant separation. For spectral reproduction, it is crucial to define an easily and rapidly invertible spectral printer model. While this is relatively straightforward with display devices, which to a certain level can be assumed to be linear and additive devices, it is still an unsolved research question to develop accurate spectral models of multi-colorant printers. The resulting spectral reflectance for a given amount of inks is severely non-linear in its nature, and depends on many complicated factors, such as dot gain and halftoning, as well as physical and optical properties of the substrate[1].

In halftone prints on paper, physical and optical dot gain generally occur, causing a tone value increase, and making the modelling of halftone colour reproduction a challenge. Optical dot gain originates from light scattering inside the substrate, causing light exchange between different chromatic areas and making the dot appear bigger than its physical size when it is perceived or measured. The effect of optical dot gain is highly non-linear and depends on the light scattering properties of the paper substrate, the halftone geometry and the halftone dot size[2].

The most comprehensive model used for multi-channel printing today is the Cellular Yule-Nielsen modified spectral Neugebauer (CYNSN) model. Since CYNSN is a forward printer model, much work is focused on different ways to invert the model to make it useful for colorant separation, by using linear regression iteration[3] or by combining the colorant separation with spectral gamut mapping[4].

There is also a colour prediction and separation model that characterizes the dot gain of each primary ink by using multiple curves, instead of only one dot gain curve which is usually utilized in other models[5,6].

A limitation of existing models is that they generally work on a point wise, or pixel wise basis, without incorporating any spatial effects. It has, however, been shown that the effect of optical dot gain very heavily depends on the local surroundings[7].

Halftoning

Colour reproduction systems mix primaries to achieve a full range of colours, modulating the relative amounts of each primary by varying the intensity at each addressable pixel and/or by some form of dithering (also known as screening or halftoning). Halftoning is a ubiquitous essential part of the printing process and has a great impact on the quality of the final reproduction product. Halftoning can be divided into two main categories, Amplitude Modulated (AM) and Frequency Modulated (FM) halftoning, with their respective advantages and disadvantages. Although AM halftoning has been the most common technique for decades, the use of FM technologies has increased during recent years. There have been many FM halftoning techniques proposed in literature[8,9,10,11]. The first real FM halftoning technique, Error Diffusion, was invented 1975[8]. Since then it has been many modifications to this algorithm trying to eliminate its shortcomings[10,11].

In the conventional colour printing, the colour separations are usually halftoned independent of each other. An interesting alternative to the conventional spectral reproduction workflow is *Spectral Vector Error Diffusion*, sVED[12]. In theory the method eliminates the need for colorant separation by combining it with the halftoning in a single step, by extending traditional error diffusion to spectral reproduction, using the spectra of all available Neugebauer primaries as criterion for selection. Another new alternative to the conventional workflow of colorant separation and halftoning is the *HANS* method, performing the halftoning in the space of Neugebauer primaries area coverage, *NPacs*, instead of colorant space[13].

Quality assessment

The usual way to evaluate the result for spectral reproductions is to print colour patches that can be measured and compared to the spectral targets, typically by computing the spectral root mean square (RMS) difference. Such measurements may indicate the spectral accuracy of the system, but not much about the image quality in general. Spectral printing will inevitably result in colour differences and various artefacts that will influence the visual quality. In order to assess whether spectral printing produce high quality images, objective quality assessment is needed. One of the methods for objective image quality assessment is image quality metrics, which have become very popular in many different fields, also for spectral evaluation[14]. However, statistically and mathematically based image metrics are usually not correlated with perceived image quality[15].

Therefore more sophisticated image quality metrics are required, which have been shown to better correlate with perceived image quality, such as S-CIELAB for halftoned images[16]. The advancements for new methods indicate potential for using image quality metrics to evaluate spectral printing, without being dependent on human observers[17,18,19]. Image quality metrics may also have the potential to be used as an optimization tool for the spectral reproduction workflow, by providing feedback that can be used in the colorant separation and halftoning process.

Project description

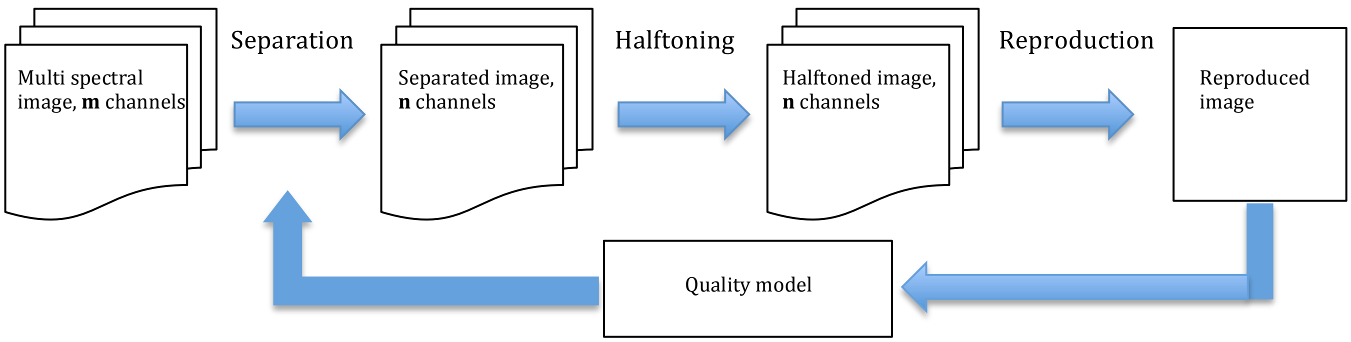

Figure 1: Multi spectral colour reproduction procedure

Theory

Figure 1 illustrates the workflow of the reproduction process of a spectral image. The original multispectral image is first separated into the colorants that the reproduction device utilizes. Then the separations are halftoned into binary images that are sent to the multichannel printer. In the reproduction, the characteristics of the printer and substrate will further affect the final result. Since all steps illustrated in Figure 1 have an impact on the image quality, there is a need for feedback and quality assessment. In this project we are facing new challenges in all steps in the reproduction process shown in Figure 1. These challenges are as follows,

Colorant separation: The most important part of this chain is the separation process. This directly affects the final result and has to be done as accurate as possible. In a conventional colour reproduction process, the input image is typically RGB and the colour differences used as criterion are CIELAB ΔE_{ab}. The separation is done in a pixel-wise manner, which means each pixel is separated independent of its neighbouring pixels.

In the proposed project, the input is a multispectral image, represented by **m** channels, i.e. each pixel is represented by its spectrum. The spectral image is then separated into **n** channels, where **n** is the number of primaries of the reproduction device. Separating a spectral image into **n** channels in a way that takes into account the characteristics of the printer, halftoning and paper substrate is complicated. Something else that has not been studied is the possibility of improving the quality by doing the separation by involving the spatial effects, i.e. in a neighbourhood dependent manner.

Halftoning: In conventional colour printing, there are usually four primary inks used, which are halftoned independently of each other. The problem with interference patterns between channels is overcome in AM halftoning by using different halftoning angles for the different colour channels. Multi-channel colour reproduction, i.e. utilizing more than the conventional four primary inks, introduces new challenges, which make FM technologies a better choice. When using multiple colorants, one of the challenges is the restriction on the number of ink layers that can be printed on top of each other. Expanding the colour gamut as much as possible is another challenge, which can for example be achieved by halftoning the colour channels dependently[20].

Quality model: Commonly, the quality model is based on the measurement of a number of reproduced training samples. Each training sample represents a colour and the goal is to minimize the colour difference between the original and the reproduced sample. In the conventional spectral colour reproduction, the goal is naturally to minimize the difference between the original spectrum and its corresponding reproduced spectrum, measured as spectral RMS difference. As discussed above, one of the goals of the proposed project is to develop new quality models that make the colour separation operate in a dependent manner to achieve better reproduction results. The other goal is to have the incorporation of the quality model as general as possible so that it can even be adapted to the need of special observers, for example persons suffering from colour deficiencies.

Method

In our previous research we separately focused on the different steps of the reproduction process. For example, we have already developed a colour prediction and separation model that work very well for both RGB and multi spectral colour images using printers with four primaries[21, 22, 23, 24]. Halftoning has also been the topic of many of our research works that resulted in a number of novel halftoning techniques and scientific articles[25,26,27,28]. In the proposed project the goal is to carry out a theoretical overall study of the whole reproduction process and examine the possibility of improving the reproduction quality by employing more efficient separation models and halftoning technologies. The most optimal separation is probably not performed in a pixel-wise manner. Different steps of the proposed project can be summarized as follows,

- Developing our existing colour separation model to be more general, i.e. its output consists of **n** channels. It has already been shown that the existing models work very well, see the preliminary results section, but they need to be used in a more general context. By using a multi channel inkjet printer the developed model can be tested.
- Developing our existing halftoning techniques to cope with the problems arising when many primaries are involved. We have access to all types of possible halftoning technologies, from AM to first generation and second generation FM and to Hybrid Halftoning, see the preliminary results section.
- Identifying important factors deciding the reproduction quality to be involved in the feedback process and examining the possibility of separating the original image by incorporating the spatial effects and a context dependent manner.
- Giving a theoretical perspective of the whole reproduction chain independent of the input and output.

Organization:

In the project we will combine the experience of the senior researchers involved in the fields of colour science, multispectral imaging, colour perception, halftoning and printing. We also plan to involve a PhD student during the last year of her PhD study.

Time plan:

When	What
Year 1	Pre-study Quality model, Assemble Spectral Test Data, Colour Separation
Year 2	Colour Separation, Halftoning, Quality Model, Validation
Year 3	Validation and Evaluation

Significance

A spectral reproduction, reproducing the spectral properties of an original, will have the significant advantage over conventional colour reproduction, that it is independent of the viewing condition. The spectral reproduction will match the original under any illumination and for any observer, including individuals with colour deficiencies. Even though today's high quality prints that are produced using conventional printing will be sufficient for most applications, a leading printer manufacturer estimates that the addressable market for spectral printing in the future could be 14% of the total print market[29]. Examples of market segments that would benefit from spectral printing include:

- *Fine-art reproduction*: With the aim to preserve cultural heritage for the future, there is an increasing amount of high quality multispectral data for fine art paintings available, which with today's technologies cannot be accurately reproduced.
- *Catalogues*: Colour differences are today a source of dissatisfied consumers and returned goods. With spectral printing in catalogues, the consumer can accurately judge the colour of a product under the illumination that it will actually be used.
- *Proofing*: Proofing is a tool for customer verification that a print job is accurate, and serves as an agreement between the customer and the printer. A spectral proof will ensure similarity to the production print, and eliminate the problems created by the influence of the illumination and viewing conditions when comparing the proof and the final product.
- *Security printing*: There is a persistent need for broadening variety of features in security printing. Spectral printing can create spectral differences among available metamers, very difficult to counterfeit, and visible only in specific illuminations.

Preliminary results

As stated before, we have already developed colour prediction and separation models for both RGB and multispectral original images[22,24]. The colour prediction model was tested using different types of halftoning (AM and FM) and with different print resolutions. For a 4-colour laser printer the average difference between the predicted and the actual colours were in all cases less than 1.7 ΔE_{ab}, which is a very good prediction result[22]. The proposed colour separation model has also been tested with good results in terms of ΔE_{ab} and spectral RMS difference[24].

FM halftoning has been one of the topics on which we have conducted research in many years. We have developed a high quality FM colour halftoning that halftones the colour separations of the image dependently, which results in better quality (less colour noise) and consumes less ink[20]. We have also examined the possibility of combining AM and FM techniques and developed a number of new hybrid techniques[25,26,28]. All these methods have been tested for different types of images and printed with different types of printers and print presses. The results of all tests showed the good performance of these techniques. During recent years we have developed a new technique, based on our previous models, which is very fast and can handle very large images.

By using a multi-channel inkjet printer that can be directly controlled by special software, we have performed practical tests of spectral colour reproduction. The performance of Spectral Vector Error Diffusion has been evaluated, and improvements to the method have been proposed to compensate for the dot gain that is inevitable in the printing process[30,31]. To reduce the problem with interference patterns such as moiré for AM halftoning, we have proposed the use of non-orthogonal screens to better separate the halftone angles for the additional colorants employed in multi-channel printing[32]. We have also proposed another method to employ in multi-channel printing based on a multi-level halftoning approach[33]. This approach was applied to achromatic inks – (PGY (light gray), GY (gray) and K (black)), (lC (light cyan), C (cyan)), (lM (light magenta), M (magenta)) – and using the multi-channel inkjet printer. Besides the method's simplicity, one of the main advantages of this approach is that no dot overlap occurred, which resulted in more homogenous prints. In addition the proposed multilevel halftoning method resulted in increased print image quality in terms of graininess and detail enhancement[33].

Equipment

Image acquisition system

In our lab we have access to an experimental image acquisition system, specially designed to capture high-resolution images. A monochrome CCD camera is equipped with high quality macro-optics, allowing for images of various magnifications, up to a maximal resolution of 1.2 μm/pixel. Colour images are captured sequentially, using filters mounted in a filter, which allows for the acquisition of multi-channel images. Models have been developed, allowing for the device dependent images to be converted into the device independent colorimetric representations and to reconstruct spectral reflectance data[35]. It is used to capture high-resolution multi-spectral images, and in our research the system has been used for printer modelling, e.g. for dot gain characterization[2,36]. Through our national and international collaborations, we have access to databases of multispectral images, as well as different systems for multispectral image acquisition that can be used to capture additional reference images for the project.

Multi-channel inkjet printer

In our lab we have a 12-channel inkjet printer Canon ipf 6400, equipped with special software that allows overriding the printer's internal settings, making it appropriate for scientific research. We have already good experience of using the system for developing and evaluating halftone routines, through our collaboration with Voxvil AB[30,31]. The possibility to control the multi-channel printer directly, using binary bitmap files for each colour channel as input, is crucial in the proposed research. The printer will be financed through the CP7.0-project.

Spectrophotometer (GretagMacbeth, Eye-One):

A spectrophotometer is a device for measuring the spectral reflectance of an object. They have their own internal light source that illuminates the samples under measurement. Based on the measured reflectance spectra they even deliver the density, CIEXYZ and CIELAB values of the samples. We do have this equipment in our lab, which has been widely used in our research to measure the printed samples to investigate the accuracy of our models.

International and national collaboration

CP7.0: Next generation multichannel printing

Colour Printing 7.0: Next Generation Multi-Channel Printing (CP7.0) is a training and research project funded by Marie Curie Initial Training Networks (ITN). The project is led by The Norwegian Colour Research Laboratory at Gjøvik University College and is executed in collaboration with 5 full network partners and 6 associated partners from academia and industry throughout Europe. Beside Linköping University and the coordinator, the full project partners are: Technische Universität Darmstadt (Germany), Voxvil AB (Sweden). University of the West of England (UK) and Océ Print Logic Technologies (France). The CP7.0-projects finances 7 PhD students and 2 Postdocs, collaborating in research on different areas associated with multi-channel printing. Linköping University is responsible for the subproject focusing on optimal halftoning algorithms and tonal reproduction characteristics of multi-channel printing.

PaperOpt

The paper optics project, which was financially supported by Vinnova, was run from 2009 until December 2012. The academic research was carried out by Mid Sweden University, Innventia, Karlstad University and Linköping University. The project aimed at modelling the paper optical system as a whole (i.e. the optical influence from all paper components and surface treatments, from printing methods and inks to measurement and evaluation) thereby facilitating efficient product development and production methods for papermaking and printing; improving printing quality and colour reproduction using lower ink consumption. LiUs part in the project was Halftone Modelling and Model Verification. There were also a number of industrial partners collaborating in the project, e.g., Stora Enso, M-Real, SCA, Korsnäs, MoRe research.

References

[1] Wyble, D. R. & Berns, R. S., “A critical review of spectral models applied to binary colour printing,” Colour Research and Application 25(1), 4-19 (2000).

[2] D. Nyström & L. Yang, “Physical and Optical Dot Gain: Separation and Relation to Print Resolution”, In N. Enlund & M. Lovrecek (Eds): Advances in Printing and Media Technology, Vol. 36, 2009, pp 337-344.

[3] P. Urban, and R. R. Grigat. "Spectral based colour separation using linear regression iteration." Colour Research & Application 31.3 (2006): 229-238.

[4] P. Urban, and R. S. Berns. "Paramer Mismatch-Based Spectral Gamut Mapping." Image Processing, IEEE Transactions on 20.6 (2011): 1599-1610.

[5] Y. Qu and S. Gooran, Simple Colour Prediction Model Based on CIEXYZ Using an Effective Coverage Map, Journal of Imaging Science & Technology, 56.1 (2012) 10506-1.

[6] Y. Qu and S. Gooran, Simple Colour Separation Model for Printing based on CIELAB and Spectral data, submitted to Journal of Imaging Science & Technology.

[7] D. Nyström, “An expanded Neugebauer formula, using varying micro-reflectance of the Neugebauer primaries”, Proc. CGIV 2012, Amsterdam, 2012, pp 157-162.

[8] Floyd, R.W.; Steinberg, L. (1975), “Adaptive Algorithm for Spatial Grey Scale.” In: Proc. International Symposium Digest of Technology, 36-37.

[9] Analoui, M.; Allebach, J. P. (1992), “Model-Based Halftoning Using Direct Binary Search.” In: Proc. Of the 1992 SPIE/IS&T Symposium, San Jose, USA, 96-108.

[10] Broja, M.; Michalowski, K; Bryngdahl, O. (1990), “Error-diffusion concept for multi-level quantization.”Opt. Commun., vol. 79, 280-284.

[11] Eschbach, R. (1997), “An Error Diffusion Algorithm with Homogeneous Response Highlight and Shadow Areas.” Journal of Electronic Imaging, 6(2), 348-356.

[12] J. Gerhardt, & J. Y. Hardeberg. "Spectral colour reproduction by vector error diffusion," Proc. CGIV, 469-473 (2006).

[13] J. Morovic, P. Morovic and J. Arnabat. "HANS: Controlling ink-jet print attributes via Neugebauer primary area coverages.", Image Processing, IEEE Transactions on 21.2 (2012): 688-696.

[14] I. Avcibas, B. Sankur, and K. Sayood. Statistical evaluation of image quality measures. Journal of Electronic Imaging, 11:206-223, 2002.

[15] D.M. Chandler and S.S. Hemami. VSNR: A wavelet-based visual signal-to-noise ratio for natural images. Image Processing, IEEE Transactions on, 16(9): 2284-2298, Sept. 2007.

[16] X. Zhang and B.A. Wandell. A spatial extension of CIELAB for digital colour image reproduction. In Soc. Inform. Display 96 Digest, pages 731-734, San Diego, 1996.

[17] M. Pedersen, Y. Zheng, and J. Y. Hardeberg. "Evaluation of image quality metrics for color prints." Image Analysis. Springer Berlin Heidelberg, 2011. 317-326.

[18] M. Pedersen and J. Y. Hardeberg. "A New Spatial Filtering Based Image Difference Metric Based on Hue Angle Weighting." Journal of Imaging Science (JIST) 56.5 (2012): 50501-1.

[19] I. Lissner and P. Urban. "Toward a unified color space for perception-based image processing." Image Processing, IEEE Transactions on 21.3 (2012): 1153-1168.

[20] S. Gooran, Dependent Colour Halftoning, Better Quality with Less Ink, Journal of Imaging Science & Technology, Volume 48, Number 4, pp. 354-362, July/August 2004.

[21] S. Gooran, M. Namedanian and Henrik Hedman, A New Approach to Calculate Colour Values of Halftone Prints, IARIGAI 36th Research Conference, Sept. 2009, Stockholm, Sweden.

[22] Y. Qu and S. Gooran, Simple Colour Prediction Model Based on CIEXYZ Using an Effective Coverage Map, Journal of Imaging Science & Technology, Vol. 56, p10506, 2012.

[23] Y. Qu and S. Gooran, Simple Spectral Colour Prediction Model using Multiple Characterization Curves, Proc. TAGA, February 2013, Portland, Oregon.

[24] Y. Qu and S. Gooran, Simple Colour Separation Model for Printing based on CIELAB and Spectral data, submitted to Journal of Imaging Science & Technology.

[25] S. Gooran, Hybrid Halftoning, A Useful Method for Flexography, Journal of Imaging Science & Technology, Volume 49, Number 1, pp. 85-95, February 2005.

[26] S. Gooran, A Novel Hybrid AM/FM Halftoning Based on Multi-level Halftoning, Journal of Imaging Science & Technology, Volume 50, Number 2, pp. 157-167, March/April 2006.

[27] S. Gooran, In Dependent Colour Halftoning, Yellow Matters, Journal of Imaging Science &

Technology, Volume 50, Number 5, pp. 448-457, September/October 2006.

[28] A. Tausif and S. Gooran, Hybrid Colour Halftoning, Proc. TAGA (Technical Association of the Graphic Arts), March 2010, San Diego, California.

[29] J. Morovic, “The Spectral Printer: From Technical Challenge to Business Case”, ROND Conference on Spectral Printing, March 14:th, Örnsköldsvik, Sweden.

[30] D. Nyström and O. Norberg, “Improved Spectral Vector Error Diffusion by dot gain compensation”, Proc. IS&T/SPIE Electronic Imaging, San Francisco, 2013.

[31] O. Norberg and D. Nyström, “Extending colour primary set in spectral error diffusion by multi level halftoning”, Proc. IS&T/SPIE Electronic Imaging, San Francisco, 2013.

[32] P. Zitinski Elias, D. Nyström and S. Gooran, “Multichannel printing by orthogonal and non-orthogonal AM halftoning”, 12:th International AIC Colour Congress, 2013.

[33] P. Zitinski Elías, S. Gooran and Daniel Nyström (2014), Multilevel halftoning applied to achromatic inks in multi-channel printing, IARIGAI 41th Research Conference, Advances in Printing and Media Technology, Sept. 2014, Swansea.

[34] P. Zitinski Elías, S. Gooran and Daniel Nyström (2015), Multilevel halftoning as an algorithm to control ink overlap in multi-channel printing, submitted to 2015 Colour and Visual Computing Symposium (CVCS), Gjøvik, Norway.

[35] D. Nyström, “Colorimetric and Multispectral Image Acquisition Using Model-based and Empirical Device Characterization”, SCIA 2007, Lec. Notes in Computer Sci. 4522, pp 798-807.

[36] M. Namedanian, and S. Gooran, "Characterization of total dot gain by microscopic image analysis." Journal of Imaging Science 55.4 (2011): 40501-40501.

Interdisciplinarity

My application is interdisciplinary

☐

An interdisciplinary research project is defined in this call for proposals as a project that can not be completed without knowledge, methods, terminology, data and researchers from more than one of the Swedish Research Councils subject areas; Medicine and health, Natural and engineering sciences, Humanities and social sciences and Educational sciences. If your research project is interdisciplinary according to this definition, you indicate and explain this here.

Click here for more information

Scientific report

Scientific report/Account for scientific activities of previous project

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Budget and research resources

Project staff

Describe the staff that will be working in the project and the salary that is applied for in the project budget. Enter the full amount, not in thousands SEK.

Participating researchers that accept an invitation to participate in the application will be displayed automatically under Dedicated time for this project. Note that it will take a few minutes before the information is updated, and that it might be necessary for the project leader to close and reopen the form.

Dedicated time for this project

	Role in the project	Name	Percent of full time
1	Applicant	Sasan Gooran	25
2	Participating researcher	Daniel Nyström	25
3	PhD Student	Paula Zitinski Elias	100

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	Total
1	Applicant	Sasan Gooran	25	342,000	350,000	358,000	1,050,000
2	Participating researcher	Daniel Nyström	25	299,000	306,000	314,000	919,000
3	PhD Student	Paula Zitinski Elias	100	736,000	0	0	736,000
	Total			1,377,000	656,000	672,000	2,705,000

Other costs

Describe the other project costs for which you apply from the Swedish Research Council. Enter the full amount, not in thousands SEK.

Premises

Type of premises	2016	2017	2018

Running Costs

	Running Cost	Description	2016	2017	2018	Total
1	Resor	Konferens	33,000	33,000	33,000	99,000
2	Publication		7,000	7,000	7,000	21,000
	Total		40,000	40,000	40,000	120,000

Depreciation costs

Depreciation cost	Description	2016	2017	2018

Total project cost

Below you can see a summary of the costs in your budget, which are the costs that you apply for from the Swedish Research Council. Indirect costs are entered separately into the table.

Under Other costs you can enter which costs, aside from the ones you apply for from the Swedish Research Council, that the project includes. Add the full amounts, not in thousands of SEK.

The subtotal plus indirect costs are the total per year that you apply for.

Total budget

Specified costs	2016	2017	2018	Total, applied	Other costs	Total cost
Salaries including social fees	1,377,000	656,000	672,000	2,705,000		2,705,000
Running costs	40,000	40,000	40,000	120,000		120,000
Depreciation costs				0		0
Premises				0		0
Subtotal	1,417,000	696,000	712,000	2,825,000	0	2,825,000
Indirect costs				0		0
Total project cost	1,417,000	696,000	712,000	2,825,000	0	2,825,000

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

The applied budget is mostly to cover the salary of the project staff. There is also a budget planned to cover publication costs and travels for conferences.

Other funding

Describe your other project funding for the project period (applied for or granted) aside from that which you apply for from the Swedish Research Council. Write the whole sum, not thousands of SEK.

Other funding for this project

Funder	Applicant/project leader	Type of grant	Reg no or equiv.	2016	2017	2018

CV and publications

CV

Sasan Gooran

1. **Masters of Science**
   1994, Computer Science and Engineering, Linköping University, Sweden

2. **PhD**
   2 March 2001, PhD dissertation, Media Technology, "High Quality Frequency Modulated Halftoning", supervised by Björn Kruse, Linköping University, Sweden

3.

4. **Docent**
   2007, Media Technology, Linköping University, Sweden

5. **Present position**
   Since May 2013, Associate Professor (Biträdande professor), Linköping University, Dept. of Science and Technology, 25% research and 75% teaching.
6. **Previous positions**
   2007-2014, Associate Professor (Docent), Linköping University, Dept. of Science and Technology, 25% research and 75% teaching.

   2001-2007 Senior lecturer, Department of Science and Technology, Linköping University.

7.

8. **Main supervisor for PhD theses**

- PhD thesis YuanYuan Qu
  Color Prediction and Color Separation Model
  Graduated: 21 October, 2013

- PhD thesis Mahziar Namedanian
  Characterization of Optical and Physical Dot Gain by Microscopic Image Analysis
  Graduated: 14 November, 2013

- PhD thesis Shahram Hauck
  Automated CtP Calibration System
  Disputation: 2015

- PhD thesis Paula Zitinski Elías
  Halftoning for Multichannel printers
  Disputation: 2016

Daniel Nyström

1. **Masters of Science**
   2002, Media Technology, Linköping University, Sweden

2. **PhD**
   16 January 2009, PhD dissertation, Media Technology, “High Resolution Analysis of Halftone Prints – A Colorimetric and Multispectral Study”, supervised by Björn Kruse, Linköping University, Sweden

3.

4.

5. **Employment**
   Since March 2014, Senior Lecturer, Linköping University, Dept. of Science and Technology, 25% research and 75% teaching.

6. **Earlier positions**
   March 2010 – February 2014, Research Associate, Linköping University, Dept. of Science and Technology, 65% research and 35% teaching.

7.

8. **Co-supervisor for PhD theses**

- PhD thesis YuanYuan Qu
  Color Prediction and Color Separation Model
  Graduated: 21 October, 2013

- PhD thesis Mahziar Namedanian
  Characterization of Optical and Physical Dot Gain by Microscopic Image Analysis
  Graduated: 14 November, 2013

- PhD thesis Paula Zitinski Elías
  Halftoning for Multichannel printers
  Disputation: 2016

Paula Zitinski Elias

1. **Masters of Science**
   2011, Computer Science, Complutense University of Madrid, Spain
   2010, Graphic Technology, University of Zagreb, Croatia

   Licentiate degree
   2014, Engineering, Linköping University, Sweden

2.

3.

4.

5. **Present position**
   Since 2012, PhD student, Linköping University, Dept. of Science and Technology, 95% research and 5% teaching.

6. **Previous employment**
   2011-2012, research fellow, Faculty of Graphic Arts, University of Zagreb, Croatia. 50% research and 50% teaching

7.

8.

Publication list

Sasan Gooran

All citation numbers are extracted from Google Scholar Citations.

Top-5 most cited publications

[1] L. Yang, S. Gooran and B. Kruse (2001), Simulations of Optical Dot Gain in Multi-chromatic Tone Reproduction, Journal of Imaging Science & Technology, Vol. 45#2, 2001. Number of citations: 26

[2] S. Gooran (2001), High Quality Frequency Modulated Halftoning, Ph.D. Dissertation No. 668, Linköping Studies in Science and Technology, Jan. 2001, ISBN 91-7219-913-X. Number of citations: 23

[3] * S. Gooran (2004), Dependent Color Halftoning, Better Quality with Less Ink, Journal of Imaging Science & Technology, Volume 48, Number 4, pp. 354-362, July/August 2004. Number of citations: 14

[4] S. Gooran, M. Österberg, and B. Kruse (1996), Hybrid Halftoning - A novel Algorithm for Using Multiple Halftoning Technologies, Proc. IS&T Int. Conf. on Digital Printing Technologies (NIP12), San Antonio, Texas, Oct. 1996, pp. 79-86. and even in: Recent Progress in Digital Halftoning II, 1999, pp. 187-194. Number of citations: 9

[5] S. Gooran, M. Namedanian and Henrik Hedman (2009), A New Approach to Calculate Colour Values of Halftone Prints, IARIGAI 36th Research Conference, Advances in Printing and Media Technology, Sept. 2009, Stockholm, Sweden. Number of citations: 6

Peer Reviewed Journal Articles, last 8 years

[1] M. Namedanian and S. Gooran (2011), Characterization of Total Dot Gain by Microscopic Image Analysis, Journal of Imaging Science & Technology, Volume 55, Number 4, July/August 2011. Number of citations: 6

[2] * Y. Qu and S. Gooran (2012), Simple Color Prediction Model Based on CIEXYZ Using an Effective Coverage Map, Journal of Imaging Science & Technology, 2012. Number of citations: 2

[3] Sh. Hauck and S. Gooran (2013), Investigation of the effect of ink penetration and gloss on a proposed spectral trapping model for high quality glossy coated paper, the Journal of print and media technology research (JPMTR), 2013, Vol. II, No. 4, 235-244. Number of citations: -

[4] Y. Qu and S. Gooran (2013), Simple color separation model based on colorimetric and spectral data, the Journal of print and media technology research (JPMTR), 2013, Vol. II, No. 2, 77-86. Number of citations: -

[5] M. Namedanian, L. G. Coppel, M. Neuman, S. Gooran, P. Edström and P. Kolseth (2013), Analysis of Optical and Physical Dot Gain by Microscale Image Histogram and Modulation Transfer Functions, Journal of Imaging Science & Technology, Volume 57, Number 2, March 2013, pp. 20504-1-20504-5(5). Number of citations: 4

[6] * S. Gooran and B. Kruse (2015), High-speed first and second-order frequency modulated halftoning, accepted for publication in the Journal of Electronic Imaging. Number of citations: -

Peer Reviewed Conference Contributions, last 8 yrs

[1] S. Gooran (2008), Optical Dot Gain and Color Halftoning with Three Different Printing Strategies: Independent, Dot-on-Dot and Dot-off-Dot, Proc. TAGA (Technical Association of the Graphic Arts), March 2008, San Francisco, California. Number of citations: -

[2] G. Baravdish, S. Gooran and B. T. Johansson (2008), A variational method for image reconstruction, The Sixth International Conference on Inverse Problems in Engineering, (Ed. M. Bonnet), Paris, France, 2008. Number of citations: 1

[3] S. Gooran, M. Namedanian and Henrik Hedman (2009), A New Approach to Calculate Colour Values of Halftone Prints, IARIGAI 36th Research Conference, Advances in Printing and Media Technology, Sept. 2009, Stockholm, Sweden. Number of citations: 6

[4] M. Namedanian and S. Gooran (2010), High Resolution Analysis of Optical and Physical Dot Gain, Proc. TAGA (Technical Association of the Graphic Arts), March 2010, San Diego, California. Number of citations: 5

[5] A. Tausif and S. Gooran (2010), Hybrid Color Halftoning, Proc. TAGA (Technical Association of the Graphic Arts), March 2010, San Diego, California. Number of citations: -

[6] M. Namedanian, S. Gooran and D. Nyström (2011), Investigating the Wavelength Dependency of Dot Gain in Color Print, SPIE, Electronic Imaging, January 2011, San Francisco, California. Number of citations: 6

[7] Y. Qu and S. Gooran (2011), A Simple Color Prediction Model based on Multiple Dot Gain Curves, SPIE, Electronic Imaging, January 2011, San Francisco, California. Number of citations: 3

[8] Sh. Hauck and S. Gooran (2011), An alternative method to determinate register variation using colorimetry or densitometry tools, Proc. TAGA (Technical Association of the Graphic Arts), March 2011, Pittsburgh, PA. Number of citations: -

[9] Sh. Hauck and S. Gooran (2011), An alternative computational method of trapping for the printers at the press, Proc. TAGA (Technical Association of the Graphic Arts), March 2011, Pittsburgh, PA. Number of citations: -

[10] S. Gooran, D. Nyström, M. Namedanian and Sh. Hauck (2011), Measuring Register Variation and Investigating its Effect on Color Appearance for Different Halftoning, Proc. TAGA (Technical Association of the Graphic Arts), March 2011, Pittsburgh, PA. Number of citations: -

[11] M. Namedanian and S. Gooran (2011), Characteristic Analysis of the Primary Color Inks in Color Print, IARIGAI 38th Research Conference, Advances in Printing and Media Technology, Sept. 2011, Budapest. Number of citations: -

[12] Sh. Hauck and S. Gooran (2011), A Networked Workflow for a Fully Automated CtP Calibration System, Proc. International Circle of Educational Institutes for Graphic Arts (IC), Sept 2011, Norrköping, Sweden. Number of citations: -

[13] Y. Qu and S. Gooran (2012), Investigating the Possibility of Using Fewer Training Samples --In the Color Prediction Model based on CIEXYZ using an Effective Coverage Map, Proc. Color in Graphics, Imaging, and Vision (CGIV), Amsterdam, May 2012. Number of citations: -

[14] M. Namedanian and S. Gooran (2013), Optical Dot Gain Study on Different Halftone Dot Shapes, Proc. TAGA (Technical Association of the Graphic Arts), February 2013, Portland, Oregon. Number of citations: -

[15] Y. Qu and S. Gooran (2013), Simple Spectral Color Prediction Model using Multiple Characterization Curves, Proc. TAGA (Technical Association of the Graphic Arts), February 2013, Portland, Oregon. Number of citations: -

[16] * P. Zitinski Elías, D. Nyström and S. Gooran (2013), Multi-channel printing by orthogonal and non-orthogonal AM halftoning, 12th International AIC Colour Congress, July 2013. Number of citations: -

[17] Y. Qu, P. Zitinski Elías and S. Gooran (2014), Color Prediction Modeling for Five-Channel CMYLcLm Printing, SPIE, Electronic Imaging, February 2014, San Francisco, California. Number of citations: 1

[18] M. Namedanian, D. Nyström, P. Zitinski Elías and S. Gooran (2014), Physical and Optical Dot Gain: Characterization and Relation to Dot Shape and Paper Properties, February 2014, San Francisco, California. Number of citations: 2

[19] O. Shayeghpour, D. Nyström and S. Gooran (2014), Improving information perception from digital images for users with dichromatic color vision, February 2014, San Francisco, California. Number of citations: -

[20] * P. Zitinski Elías, S. Gooran and Daniel Nyström (2014), Multilevel halftoning applied to achromatic inks in multi-channel printing, IARIGAI 41th Research Conference, Advances in Printing and Media Technology, Sept. 2014, Swansea. Number of citations: -

Book chapter

[1] S. Gooran and L. Yang (2015), Basics of tone reproduction, Handbook of Digital Imaging. Wiley, ISBN: 978-0-470-51059-9.

Daniel Nyström

All citation numbers are extracted from Google Scholar Citations.

Top-5 most cited publications

[1] D. Nyström, Colorimetric and Multispectral Image Acquisition. Licentiate Thesis No. 1289, Linköping University, 2006. Number of citations: 10.

[2] * D. Nyström, "Colorimetric and Multispectral Image Acquisition Using Model-based and Empirical Device Characterization", In B.K. Ersboll & K.S. Pederson (Eds): SCIA 2007, Lecture Notes in Computer Science 4522, pp 798-807. Number of citations: 9.

[3] * D. Nyström & L. Yang, "Physical and Optical Dot Gain: Separation and Relation to Print Resolution", In N. Enlund & M. Lovrecek (Eds): Advances in Printing and Media Technology, Vol. 36, 2009, pp 337-344. Number of citations: 7.

[4] M. Namedanian, S. Gooran, and D. Nyström, "Investigating the Wavelength Dependency of Dot Gain in Color Print". Proc. IS&T/SPIE, Electronic Imaging Sci. Technol., 2011, 7866, No. 786617. Number of citations: 6.

[5] * D. Nyström, "An expanded Neugebauer formula, using varying micro-reflectance of the Neugebauer primaries", Proc. CGIV 2012 - 6:th European Conference on Colour in Graphics, Imaging, and Vision, Amsterdam, 2012, pp 157-162. Number of citations: 5.

Peer Reviewed Conference Contributions, last 8 years

[1] D. Nyström, "Reconstructing Spectral and Colorimetric Data Using Trichromatic and Multi-channel Imaging", Proc. Ninth International Symposium on Multispectral Color Science and Application, Taipei, 2007, pp 45-52. Number of citations: 4.

[2] * D. Nyström, "Colorimetric and Multispectral Image Acquisition Using Model-based and Empirical Device Characterization", In B.K. Ersboll & K.S. Pederson (Eds): SCIA 2007, Lecture Notes in Computer Science 4522, pp 798-807. Number of citations: 9.

[3] D. Nyström, B. Kruse, and L. Yang, "A Micro-Scale Study of Optical Dot Gain in Color Halftone" In N. Enlund & M. Lovrecek (Eds): Advances in Printing and Media Technology, Vol. 34, 2007, pp 271-179.

[4] D. Nyström, “A Close-Up Investigation of Halftone Color Prints” Proc. TAGA (Technical Association of the Graphic Arts), San Francisco, 2008, pp 347-363. Number of citations: 1.

[5] D. Nyström, “A Micro-scale View on Color Reproduction” Proc. CGIV 2008 - IS&T’s Fourth European Conference on Colour in Graphics, Imaging, and Vision, Terassa, 2008, pp 542-547. Number of citations: 5.

[6] D. Nyström & L. Yang, “Dot Gain and Screen Resolution”, Proc. IMQA 2008 - The Third International Workshop on Image Media Quality and its Applications, Kyoto, 2008, pp 45-50. Number of citations: 1.

[7] * D. Nyström & L. Yang, “Physical and Optical Dot Gain: Separation and Relation to Print Resolution”, In N. Enlund & M. Lovrecek (Eds): Advances in Printing and Media Technology, Vol. 36, 2009, pp 337-344. Number of citations: 7.

[8] D. Nyström, “Microscopic Color Measurements of Halftone Prints”, Proc. NIP26 – 26th International Conference on Digital Printing Technologies, Austin, 2010, pp 459-462. Number of citations: 4.

[9] M. Namedanian, S. Gooran, and D. Nyström, “Investigating the Wavelength Dependency of Dot Gain in Color Print”. Proc. IS&T/SPIE, Electronic Imaging Sci. Technol., 2011, 7866, No. 786617. Number of citations: 6.

[10] D. Nyström, “Micro-reflectance Measurements of Multiple Colorants in Halftone Prints”, Proc. TAGA (Technical Association of the Graphic Arts), Pittsburgh, 2011, pp. 157-176. Number of citations: 3.

[11] S. Gooran, D. Nyström, M. Namedanian and S. Hauck, “Measuring Register Shift and Investigating its Effect on Color Appearance for Different Halftoning”, Proc. TAGA (Technical Association of the Graphic Arts), Pittsburgh, 2011, pp. 225-232.

[12] Y. Y. Qu, D. Nyström and B. Kruse, ”A New Approach to Estimate the 3-D Surface of Paper”, Proc. TAGA (Technical Association of the Graphic Arts), Pittsburgh, 2011, pp. 321-339

[13] * D. Nyström, “An expanded Neugebauer formula, using varying micro-reflectance of the Neugebauer primaries”, Proc. CGIV 2012 - 6:th European Conference on Colour in Graphics, Imaging, and Vision, Amsterdam, 2012, pp 157-162. Number of citations: 5.

[14] O. Norberg & D. Nyström, "Spectral Vector Error Diffusion - Promising Road or Dead End?", Proc. CIC 20 – Twentieth Color and Imaging Conference, Los Angeles, 2012, pp 329-334. Number of citations: 2.

[15] * D. Nyström & O. Norberg, "Improved Spectral Vector Error Diffusion by dot gain compensation", Proc. IS&T/SPIE Electronic Imaging, San Francisco, 2013. Number of citations: 1.

[16] O. Norberg & D. Nyström, "Extending color primary set in spectral error diffusion by multi level halftoning", Proc. IS&T/SPIE Electronic Imaging, San Francisco, 2013.

[17] P. Zitinski Elias, D. Nyström and S. Gooran, "Multichannel printing by orthogonal and non-orthogonal AM halftoning", Proc. AIC Colour 2013 – 12th Congress of the International Colour Association, 2013, pp. 597-600.

[18] M. Namedanian, D. Nyström, P. Zitinski Elías and S. Gooran, "Physical and Optical Dot Gain: Characterization and Relation to Dot Shape and Paper Properties", Proc. IS&T/SPIE Electronic Imaging, San Francisco, 2014. Number of citations: 2

[19] O. Shayeghpour, D. Nyström and S. Gooran, "Improving information perception from digital images for users with dichromatic color vision", Proc. IS&T/SPIE Electronic Imaging, San Francisco, 2014.

[20] P. Zitinski Elías, S. Gooran and Daniel Nyström, "Multilevel halftoning applied to achromatic inks in multi-channel printing" Proc. IARIGAI 41th Research Conference, Advances in Printing and Media Technology, Swansea, 2014.

Other publications, last 8 years

[1] D. Nyström, "Micro-Scale Characteristics of Color Prints", Proc. SSBA Symposium on Image Analysis, Linköping, 2007, pp 33-36. Number of citations: 1.

[2] * D. Nyström, High Resolution Analysis of Halftone Prints – A Colorimetric and Multispectral Study. Ph.D. thesis, Dissertations No. 1229, Linköping University, 2008. Number of citations: 3.

[3] D. Nyström, "Using Microscopic Images in Color Print Research", Proc. The 42nd International Circle Conference, Moscow, 2010, pp 110-115.

[4] M. Namedanian, S. Gooran, and D. Nyström, “Wavelength Dependency of Light Scattering in Halftone Color Print”. Proc SSBA Symposium, Linköping, 2011.

[5] Y. Y. Qu, D. Nyström and B. Kruse, ”Estimate the 3-D surface of uncoated paper using photometric stereo method”, Proc SSBA Symposium, Linköping, 2011.

Paula Zitinski Elias

All citation numbers are extracted from Google Scholar Citations.

Top-5 most cited publications

[1] T. Tomasegovic, P. Zitinski Elias, M. Baracic and M. Mrvac (2011), E-learning and evaluation in modern educational system, US-China Education Review, Vol. 8#2, 2011. Number of citations: 9

[2] M. Baracic, T. Cigula, T. Tomasegovic, P. Zitinski Elias and M. Gojo (2009), Influence of Plate Making Process and Developing Solutions on the Nonprinting Areas of Offset Printing Plates, Annals of DAAAM for 2009, Vol. 20#1, 2009. Number of citations: 7

[3] M. Namedanian, D. Nyström, P. Zitinski Elías and S. Gooran (2014), Physical and Optical Dot Gain: Characterization and Relation to Dot Shape and Paper Properties, February 2014, San Francisco, California. Number of citations: 2

[4] * Y. Qu, P. Zitinski Elías and S. Gooran (2014), Color Prediction Modeling for Five-Channel CMYLcLm Printing, SPIE, Electronic Imaging, February 2014, San Francisco, California. Number of citations: 1

[5] * P. Zitinski Elias, D. Nyström and S. Gooran (2013), Multichannel printing by orthogonal and non-orthogonal AM halftoning, AIC 2013 – The 12:th International AIC Colour Congress, July 2013, Newcastle, UK. Number of citations: 1

Peer Reviewed Journal Articles

[1] T. Tomasegovic, P. Zitinski Elias, M. Baracic and M. Mrvac (2011), E-learning and evaluation in modern educational system, US-China Education Review, Vol. 8#2, 2011. Number of citations: 9

Peer Reviewed Conference Contributions

[1] P. Zitinski Elías, T. Tomasegovic and D. Modric (2008), Modelling of Dispersion and Reflection of Light on Paper Surface, Proc. 19th International DAAAM Symposium, October 2008, Trnava, Slovakia. Number of citations: -

[2] P. Zitinski Elías, T. Tomasegovic and T. Cigula (2009), Differences in Physical-Chemical Properties of the Nonprinting Areas for Conventional and CtP Process, Proc. 3rd International Student Conference on Print and Media Technology, May 2009, Chemnitz, Germany. Number of citations: -

[3] T. Tomasegovic, P. Zitinski Elías, M. Baracic and T. Cigula (2010), Influence of the printing media on the properties of fountain solution, Proc. 13th International conference of printing, design and graphic, May 2010, Novi Sad, Serbia. Number of citations: -

[4] M. Bukal Hetrich, P. Zitinski Elías and K. Golubovic (2010), The influence of printing resolution on specific tone values printed with UV curing inkjet, Proc. International Student Congress of Graphic Technologies PDP Convention, May 2010, Novi Sad, Serbia. Number of citations: -

[5] P. Zitinski Elías, D. Agic, L. Mandic, M. Strgar Kurecic and A. Poljicak (2011), Web Engineering Requirements in Web Application Development, Proc. Printing Future Days 2011, October 2011, Chemnitz, Germany. Number of citations: -

[6] P. Zitinski Elías, A. Poljicak, M. Strgar Kurecic and L. Mandic (2011), Behavior of Web Safe Colors with Different Print Production Profiles, Annals of DAAAM for 2011, November 2011, Vienna, Austria,. Number of citations: -

[7] P. Zitinski Elías, A. Poljicak, L. Mandic and M. Strgar Kurecic (2012), The measurement of diverse displays' colorimetric characteristics, ELMAR, 2012 Proceedings, September 2012, Zadar, Croatia. Number of citations: -

[8] P. Zitinski Elias, D. Nyström and S. Gooran (2013), Multichannel printing by orthogonal and non-orthogonal AM halftoning, AIC 2013 – The 12:th International AIC Colour Congress, July 2013, Newcastle, UK. Number of citations: 1

[9] Y. Qu, P. Zitinski Elías and S. Gooran (2014), Color Prediction Modeling for Five-Channel CMYLcLm Printing, SPIE, Electronic Imaging, February 2014, San Francisco, California. Number of citations: 1

[10] M. Namedanian, D. Nyström, P. Zitinski Elías and S. Gooran (2014), Physical and Optical Dot Gain: Characterization and Relation to Dot Shape and Paper Properties, February 2014, San Francisco, California. Number of citations: 2

[11] * L. Gustafsson Coppel, S. Le Moan, P. Zitinski Elías, and R. Slavuj (2014), Next generation printing - Towards spectral proofing, IARIGAI 41th Research Conference, Advances in Printing and Media Technology, September 2014, Swansea, UK. Number of citations: -

[12] * P. Zitinski Elías, S. Gooran and D. Nyström (2014), Multilevel halftoning applied to achromatic inks in multi-channel printing, IARIGAI 41th Research Conference, Advances in Printing and Media Technology, September 2014, Swansea. UK. Number of citations: -

Other publications

[1] P. Zitinski Elías (2008), Utjecaj vremena osvjetljavanja analognih tiskovnih formi na kontaktni kut, Bachelor thesis, University of Zagreb, 2008. Number of citations: -

[2] P. Zitinski Elías (2010), New Approach of Examination Functional Qualification of Fountain Solutions, Master thesis, University of Zagreb, 2010. Number of citations: -

[3] P. Zitinski Elías (2010), Fusión de imágenes mediante wavelets para extracción de las partes verdes en imágenes agrícolas, Master thesis, Complutense University of Madrid, 2011. Number of citations: -

[4] P. Zitinski Elías (2014), Halftoning for Multi-Channel Printing: Algorithm Development, Implementation and Verification, Licentiate thesis no. 1694, Linköping University, 2014. Number of citations: -

CV

Name: Sasan Gooran	**Doctorial degree:** 2001-03-02
Birthdate: 19650816	**Academic title:** Docent
Gender: Male	**Employer:** Linköpings universitet

Research education

Dissertation title (swe)

Dissertation title (en)

Organisation	Unit	Supervisor
Linköpings universitet, Sweden Sweden - Higher education Institutes	Institutionen för teknik och naturvetenskap (ITN)	

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
21102. Mediateknik		2001-03-02

CV

Name: Daniel Nyström	**Doctorial degree:** 2009-01-16
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Gender: Male	**Employer:** No current employer

Research education

Dissertation title (swe)		
Dissertation title (en)		
High Resolution Analysis of Halftone Prints - A Colorimetric and Multispectral Study		
Organisation	**Unit**	**Supervisor**
Linköpings universitet, Sweden Sweden - Higher education Institutes	Institutionen för teknik och naturvetenskap (ITN)	Björn Kruse
Subject doctors degree	**ISSN/ISBN-number**	**Date doctoral exam**
21102. Mediateknik	978-91-7393-727-6	2009-01-16

Publications

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Gooran, Sasan has not added any publications to the application.

Publications

Name: Daniel Nyström	**Doctorial degree:** 2009-01-16
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Nyström, Daniel has not added any publications to the application.

Register

Terms and conditions

The application must be signed by the applicant as well as the authorised representative of the administrating organisation. The representative is normally the department head of the institution where the research is to be conducted, but may in some instances be e.g. the vice-chancellor. This is specified in the call for proposals.

The signature*from the applicant*confirms that:

- the information in the application is correct and according to the instructions form the Swedish Research Council
- any additional professional activities or commercial ties have been reported to the administrating organisation, and that no conflicts have arisen that would conflict with good research practice
- that the necessary permits and approvals are in place at the start of the project e.g. regarding ethical review.

The signature *from the administrating organisation* confirms that:

- the research, employment and equipment indicated will be accommodated in the institution during the time, and to the extent, described in the application
- the institution approves the cost-estimate in the application
- the research is conducted according to Swedish legislation.

The above-mentioned points must have been discussed between the parties before the representative of the administrating organisation approves and signs the application.

Project out lines are not signed by the administrating organisation. The administrating organisation only sign the application if the project outline is accepted for step two.

Applications with an organisation as applicant is automatically signed when the application is registered.