Industrial Applications of Spectral Color Technology

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Abstract

In this paper, we will present industrial applications of spectral color technology. The applications are realized in InFotonics Center Joensuu, which is a research center at the University of Joensuu, Finland. I will show examples of the research projects, in which we are working together with industry's R&D. The aim of this paper is to present the innovation environment how University is doing industrial cooperation and the examples of research projects.

Introduction

The spectral measurement and imaging devices are becoming more and more convenient to be used in industrial applications. The price and the size of devices is now leading towards the industrial use. Also the CIE has founded recently a technical committee for multispectral imaging.

The long term research since the middle of 1980's in the field of spectral color research at the University of Joensuu lead to industrial cooperation only a few years ago. Much earlier the photonics field at the University of Joensuu had started the industrial cooperation. There was a clear need for a research center that will concentrate to the industrial cooperation.

Based on this, the InFotonics Center Joensuu was founded in autumn 2003 to serve as a link between the University research and the industry. The center has 10 people working, who are concentrated in industrial cooperation. Director, principal scientist, laboratory engineer and planning officer of the center are concentrated in all research projects and other researchers are hired for more specific research themas. The center has resources from the optics group of the Department of Physics and Mathematics, in which there are about 70 people working and from the spectral color research group that is a joint group of 25 people of the Department of Computer Science and Statistics and the Department of Physics and Mathematics. The Research Liaison Office of the University of Joensuu is helping in contract, NDA, innovation, and patenting related matters and the Joensuu Science Park is helping in marketing and commercialization matters. Since 1997 we have generated 4 spin-off companies from our research fields. Three of these are in photonics field, Nanocomp Ltd., Optoinspection Ltd., MGM-Devices Ltd., and one in color field, SoftColor Ltd. All companies have been founded by University researchers and they have started their business via the business incubator of the Joensuu Science Park. The basic funding for InFotonics Center staff is coming from European Union Structural Funds, from Eurogio Karelia Neighbourhood programme and from the Finnish Funding Agency for Technology and Innovation (Tekes). Other partners in basic funding are the City of Joensuu and the Joensuu Regional Development Company (JOSEK), which are regional funders. Industrial partners are funding about 10% of the total basic funding.

Since 2003, the InFotonics Center Joensuu has done over 40 feasibility studies and concept developments related to photonics and spectral color research. In many of these feasibility studies, the color has been the quality measure in industrial process. The feasibility studies have been short-term, in which the industrial partner has had a problem or task, in which we have applied our existing research results. In addition, the center has generated long-term applied research projects together with other scientific organizations and with industrial partners. In these projects, we are hiring Dr. students, and the topic of the research project is linked near to the topic of the

Dr. thesis. In this way, the industrial cooperation is also supporting the research at the University. Next, I will describe the spectral imaging systems and our case studies of industrial applications.

Spectral Imaging Systems

In our research, we measure the color as accurately as possible, i.e. as a spectral color. In point measurements, spectrophotometer, spectroradiometer, and spectrometers are used. In imaging tasks, the spectral images are acquired. The spectral image contains color spectrum in every pixel of the image. These images can be measured by spectral imaging systems, which can be, for example, filter based systems, such as Liquid Crystal Tunable Filter (LCTF) or Acousto-Optical Tunable Filters (AOTF), or line scanning based systems, such as ImSpector-based spectral cameras. In ImSpector-based systems [1] the light from one line of the object is conveyed via the slit through the Prism-Grating-Prism (PGP) element to the two-dimensional CCD-array. One axis in the CCD-array is used for spatial information and one axis is used for spectral information. The system needs mechanical scanning in spatial domain. An example of the line scanning based system, which has been used in the experiments in this paper, is shown in Figure 1. Linear stages are needed to move the sample, illumination is in 45 degree angle to the object, and the spectral camera is scanning the spectral image of the sample, line by line.

For the automatic spectral image acquisition, we have programmed software in our laboratory. The software controls the linear stages and the spectral camera so that the line scanning and imaging are done in synchronized way. We can also take high-resolution images by this system by scanning the object in slices and then the slices are combined together by automatic software. Figure 2 shows an user interface of the program that controls the spectral imaging system.

After the imaging, our software shows the scanned spectral image as RGB-representation, in which user can change different light sources and also CIE xyY and CIELAB color coordinate systems with different light sources of the spectral image can be shown. Figure 3 shows an user interface of this software.

We are using three different types of ImSpector cameras, one is for visible wavelength area from 380nm to 780 nm, one is for visible and near infrared area from 400nm to 1000nm and one is for infrared area from 950nm to 1700nm. The spectral resolutions of the cameras are 4nm, 2.8nm, and 5nm, respectively.

Figure 1. Spectral imaging system.

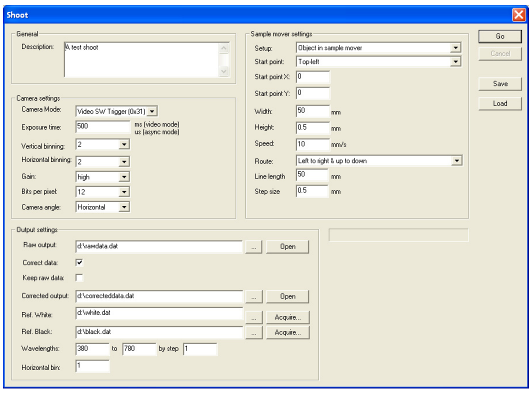


Figure 2. User interface of the developed software for spectral image acquisition.

Recently, we constructed a spectral imaging system for the wavelength area from 400nm to 1700nm by combining two ImSpector-based camera systems together [2]. The software for combining the measured data from the same line by two different spectral cameres was also developed. The industrial interest towards the visible and infrared imaging of the same object is growing, for example, in paint and plastics industry. Figure 4 shows this spectral imaging setup.

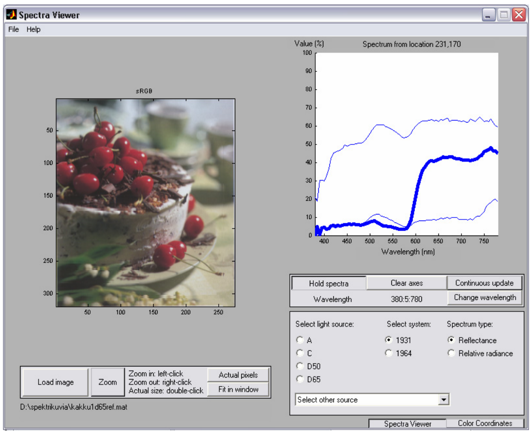


Figure 3. User interface of the developed software for viewing the measured spectral image.

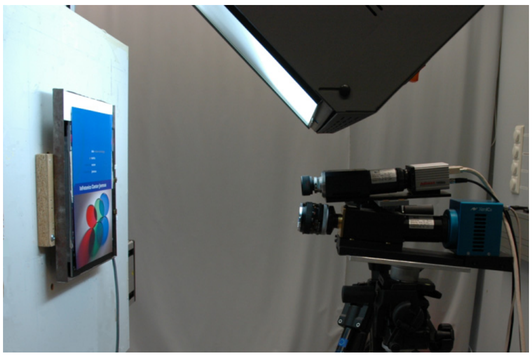


Figure 4. Spectral imaging system from 400nm to 1700nm.

Case studies

Next, some case studies of the industrial applications done at the InFotonics Center are presented. These studies have been done together with plastics industry, paper industry, and stone industry.

Case 1: Plastics industry

Figure 5 shows an example of the spectral imaging system that was used in industrial robot arm. In this study, we had the 3D-shape as a CAD-file of the plastic target, which is covered in the Figure 5. The robot arm was moving line by line based on the shape of the surface of the object. By this setup the focus and the measurement geometries were kept constant in every line. Light source here was illuminating only the line that was under measuring. The aim in this project was to study the spectral differences between objects with curved surfaces. The customer needed absolute spectral information in order to see the differences under different illuminations.

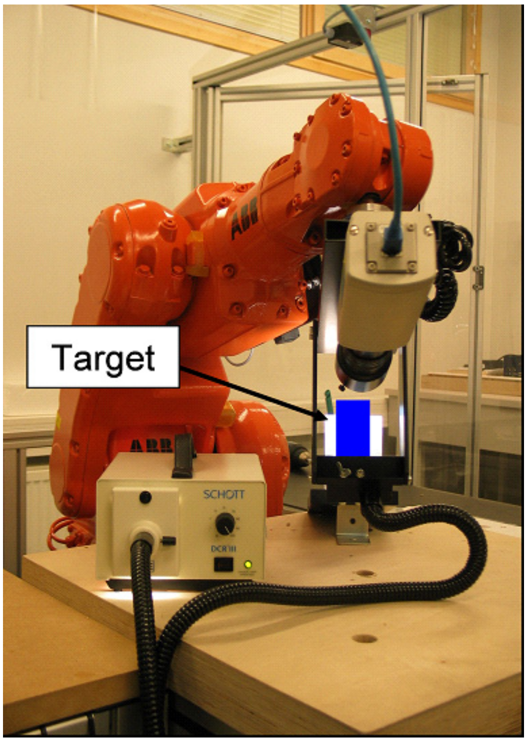


Figure 5. Experiments with industrial robot arm.

The next feasibility study we made also together with plastics industry. In this cooperation, the goal was to implement the system for quality control in which the color of the plastics objects needed to be checked. The spectral imaging system shown in Figure 1 was used. The screenshot of the user interface of the developed software is shown in Figure 6. In this software, the acceptance limits of CIELAB color coordinates L*, a*, and b* are defined manually, which are usually got from the customer of that plastics product. The software shows the areas of the plastics product which are not in the range of the accepted CIELAB coordinates. If the color of the objects is in the acceptable range, then the system accepts the color of the product. Because the spectral reflectance data is measured, the CIELAB coordinates can be analyzed under different light sources.

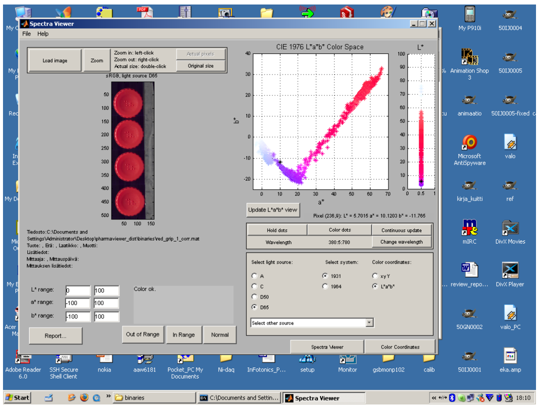


Figure 6. User interface screenshot of the spectral color based quality control software.

Case 2: Spectral based monitoring of laser welding

In this project, we are cooperating with the Department of Mechanical Engineering, Lappeenranta University of Technology, Finland. The goal in this project is to do online monitoring of laser welding process [3]. Figure 7 shows the testing environment for laser welding process. Two metal parts are welded together with laser and three spectral measurement systems are monitoring the welding. One system is fiberoptic spectrometer, one is spectral camera in the visible wavelength area and one is spectral camera in the infrared area.

Figure 8 shows an example of the laser welding in progress. The white cloud is measured and the properties of it are analyzed. In Figure 9, two spectra are shown. Red spectrum correcponds to the good welding named as reference and blue spectrum corresponds to the welding in which the failure to the welding was generated artificially. These failures include, for example, the laser power changes, welding speed changes and so on. The goal in this project is to study different failure situations that could be spectrally monitored. If the failures are in specific wavelength area, then the sensor detecting that wavelength could be realized. In this project the companies from welding, automotive, and detector development are participating. Funding for the project comes from the Finnish Funding Agency for Technology and Innovation (Tekes) as 80 % and 20 % of the funding comes from the industry.

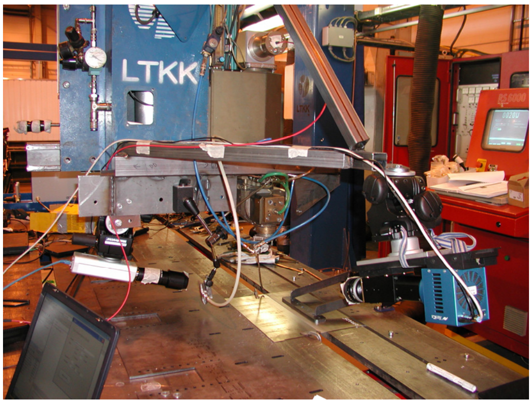


Figure 7. Spectral based monitoring of laser welding.

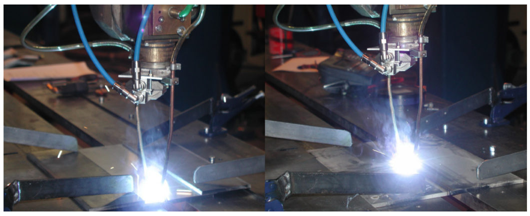


Figure 8. Laser welding in progress.

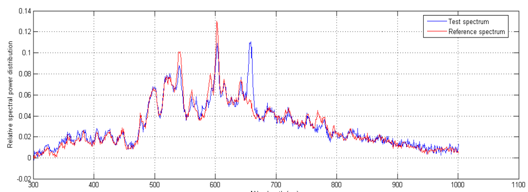


Figure 9. Spectra from the reference welding and from the test welding.

Case 3: Optimizing the images for displays

In this case study, we present results for optimizing images for an industrial show room [4]. The light conditions at the show room were not very controllable and the projector was not a high quality one. The optimization was done using metameric reproduction [5,6] and to do this we measured spectral information of the product, projector, and the illumination at the show room. The spectral characteristics of the red channel of the projector was problematic: range of possible red values was narrower than the green and blue range. This caused some limitations which needed to be taken into account in calculating the optimal images: optimal images can have either full contrast range with a reddish tint or correct hue with narrower contrast range. Figure 10 shows examples of two optimized images of the soapstones which are the products of our cooperating company. In this project, totally 100 soapstones were imaged as spectral images and they were optimized for the data projector at the showroom conditions.

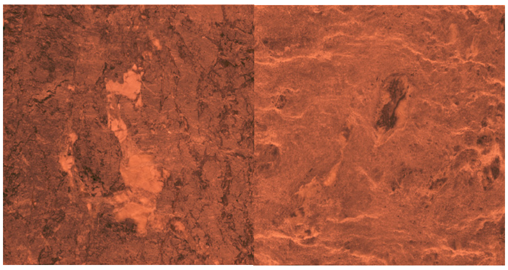
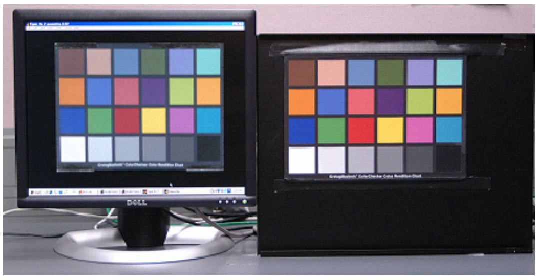


Figure 10. Optimized images of soapstones.

The same idea presented in the previous example was applied for printing industry, in which the color checker had to be optimized for LCD-display. The external illumination in the room had also been taken into account. This study can be applied for electronic pre-prints, for example. Figure 11 shows the examples of the optimizations.

This idea has been also applied for optimizing the backprojection system. Figure 12 shows examples for face images. Here the face has been measured as spectral image, and the color production properties of the data projector and the external illumination has also been taken into account. Applications of this case study can be, for example, in telemedicine, where skin color is the basis for diagnosis.



a)

b)

Figure 11. Optimized images for LCD-display, for external illumination a) D65, b) tungsten lamp.

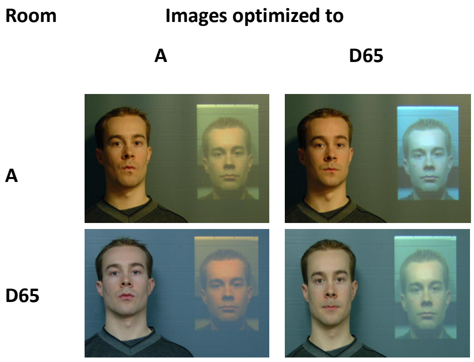


Figure 12. Face spectral image characterization.

In addition to the examples of the optimal characterization of images for displays presented here, we have done spectral color based color characterization for cultural historical documentation and for medicine. For example, we have implemented the FM-100 color vision test for computer display, in which the user selects the order of the color patches by mouse. All color patches of FM-100 test were measured spectrally and the images of them were shown as color characterized. The results have been compared with the FM-100 test done under the lightbooth illumination, and the correlation of the results is promising.

Case 5: Other studies

At the moment we are have applied research projects in which the spectral color technologies are applied for future steel frontages, for digital museum, for paper and printing industry, for wood humidity analysis, for automotive industry, and for retinal image analysis of diabetes. In all of these projects, other scientific organizations and industrial partners are participating.

Also the fluorescence analysis based on spectral information measured by bispectrometer is now growing topic, for example, in the field of biophotonics. We have recently built a bispectrometer device for these measurements and that have been used for optical brightening agent studies for paper industry, for mineral analysis, and for plastics industry. The measurement accuracy of 2.5nm can be achieved by the system, which is important in narrow fluorescence peak analysis.

Conclusion

In this paper, we presented case studies of applied research projects at the InFotonics Center Joensuu, Finland. In these projects, the spectral color research is applied for industrial processes. The advantages of the spectral color based systems are that the most accurate color representation is acquired and it can then be filtered for specific purposes, such as for displaying the color characterized image. We can also find from the spectral data the optimal wavelength areas to be detected, and therefore, the final sensor used in industrial process can be simple detector optimized for specific wavelength area. In Joensuu, Finland, we have possibilities for manufacturing optical components based on diffractive optics, that can be used as optimal gratings in sensors. Also the massproduction of these diffractive optical elements is possible in Joensuu. All this is based on long term research done at the University of Joensuu. Due to the technical development of spectral imaging systems, they are becoming more and more possible to be used in online processes, also.

Acknowledgements

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