MESOSCOPY: A NEW APPROACH FOR INDUSTRIAL IN-LINE INSPECTION

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Abstract

In this paper we propose a system for in-line inspection of high precision production systems. Mesoscopes, in analogy with microscopes are systems that can visualize surface areas with dimensions of a few meters with the ability to bring into focus meso-structures of a few microns using visible light spectroscopy. We present systems developed at Kyoto University and discuss the potential applications in display production industry and cultural heritage investigations.

Keywords: Analytical imaging, High-resolution scanning, In-line inspection, Mesoscopy

Introduction

In recent years, an extremely rapid development in imaging systems has taken place. The fast progresses in consumer imaging products such as digital cameras, SLRs, and Video movie cameras are very visible in our daily lives [1]. The more sophisticated industrial imaging systems have also the progressed on the same level or even faster. These progresses are due to CCD devices (or CMOS) with extremely good quality and software programs with high dynamic capabilities [2-5]. In this paper we would like to present a new idea, based on the advancement of imaging devices and systems for industrial applications.

Mesoscopy is the science of bringing into sight the details in microscopic level of objects that are in dimensions of a few meters, and the mesoscope is the device used for this purpose. The term mesoscope that we use in our work is in analogy to the optical microscope. Optical microscopes that are used in daily industrial inspection process can give high-resolution images of low focal distances and narrow field of vision. Mesoscopic imaging has already been widely used in biology but is still considered to be in its infancy compared to macroscopic, microscopic and even nanoscopic imaging [6]. An example of mesoscopic imaging in industrial inspection is given as follows: imagine a 65-inch display system that needs to be investigated in detailed level of a single plasma cell (about a few 10 micrometers), while having access to information all over the display panel area. Conventional photography could give an image of the whole panel but has a very limited spatial resolution. It cannot show the details at the microscopic level. On the other hand, a microscope would be able to give the desired spatial resolution to look into the details of the object but has very limited range. The viewing area is almost concentrated within a single point.

Another example of how mesoscopic imaging could be used for analytical imaging is the investigation of surface textures of a traditional Korean paper. A sheet of paper with the size of 90 x 120 cm is digitized (Figure 1). Ultra-high resolution imaging enables us to see the microscopic details of textures clearly, in any arbitrary point on the image. In addition, by playing with how the object is illuminated, other analytical information about the object could be extracted. Figure 2 shows a reflected light image of the same paper, and Figure 3 shows a transmitted light image. A mesoscopic system is capable of bridging the gap between the macro- and the micro- dimensions of different materials. This characteristic makes mesoscopic imaging a suitable tool for in-line industrial inspections and diagnostics.

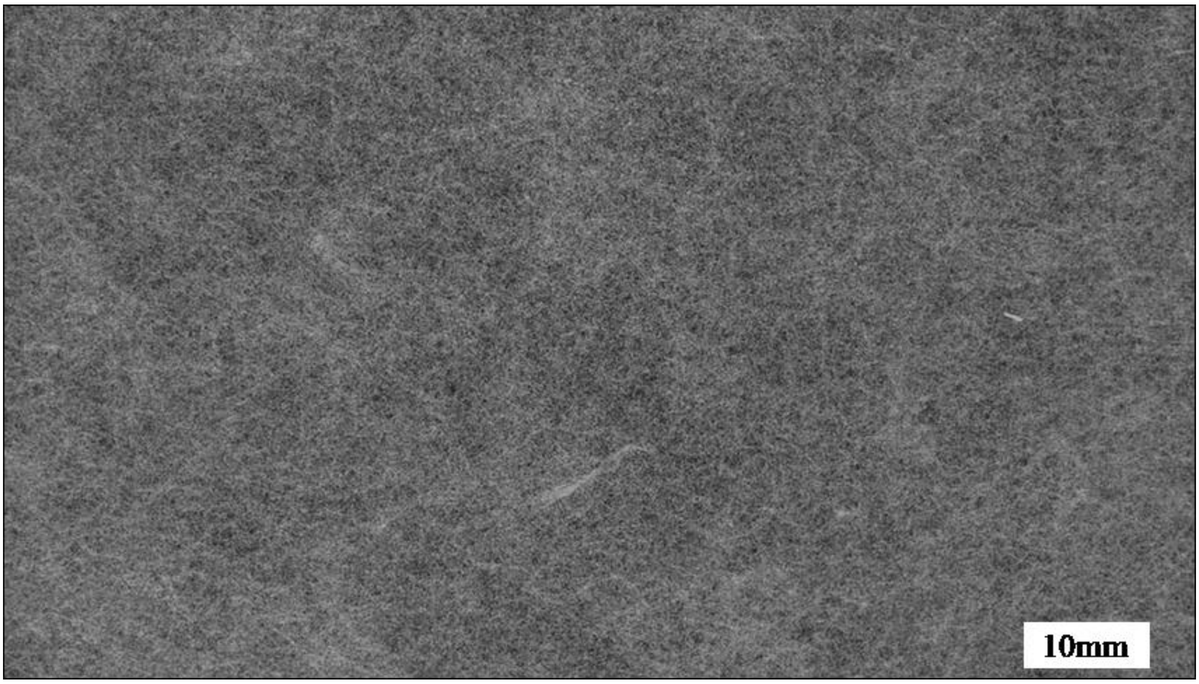


Figure 1. An ultrahigh resolution scanned image of a Korean paper (~90cm x 120cm)

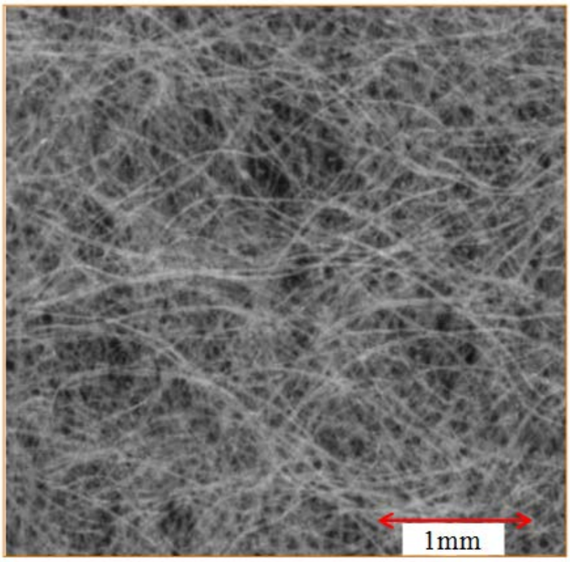


Figure 2. Enlarged reflection image of the Korean paper

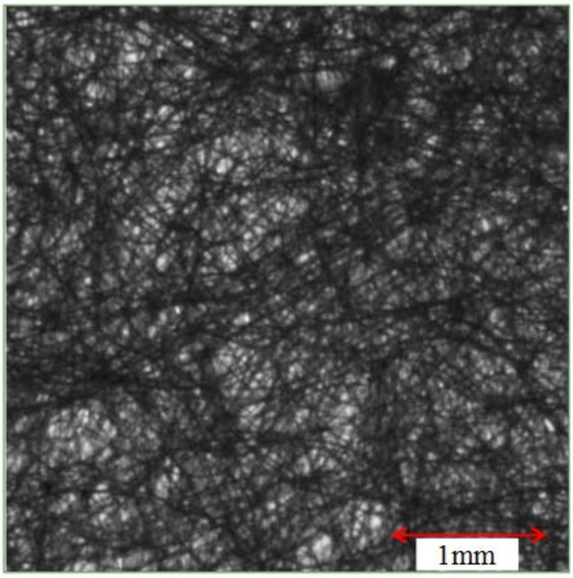


Figure 3. Enlarged transmission image of the Korean paper

Experimental Set-Up

Multipurpose Test Stand

Figure 4 shows our multipurpose test stand for the diagnosis of large-sized objects (e.g. few meters in dimension). It is a flat-bed scanner equipped with state-of-the-art imaging devices for achieving high quality images at high to ultrahigh resolutions. The system can accommodate virtually any size of sample and is only practically limited by the testing space. It does not have a limit on the size of the sample but the system shown in Figure 4 has an effective imaging area of about 90 x 180cm. This could easily be extended by placing the entire assembly in a pair of rails. The total time required for imaging an entire object with 2 x 1m dimension at 600dpi is 15 minutes. The system has a single image sensor but it can be used as a multi-head imaging sensor system.

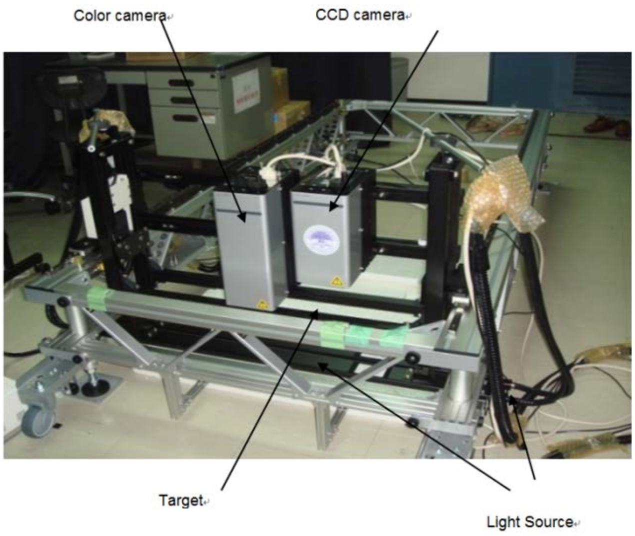


Figure 4. Photograph of Kyoto University's mesoscopic system: an ultrahigh-resolution scanning system used for inspecting large objects in detail

System Constituent Parts

The system consists of the following software, firmware and hardware.

- Firmware: motor drivers, sensors controllers, light controller, image acquisition software and controllers
- Software: Shading, color management software, other applications
- Hardware: CCD sensor, lens system, camera box, motors, main frame, camera frame

The high resolution imaging system (mesoscope) is strongly affected by the vibrations and the motions of the system especially when the resolution is above 1000 dpi.

Sample Applications of the System

The system can be used to diagnose the following parameters at a single pixel level:

- The shape, and defect of each single set of RGB pixels
- The brightness and colorimetric values of each pixel
- Reflection image
- Transmission image
- Polarized image
- Multispectral image

Currently we are using the system in various fields.

i) Color evaluation of LED and degradation of colorants
ii) Display panels inspection
iii) Inspection of medium-sized 3D industrial objects
iv) Imaging and conservation of cultural heritage
v) High resolution (10-20 micrometer level) spectrometry
vi) Imaging of biological samples (e.g. butterfly wings, bugs and insects)

In this paper, two out of the six different fields listed above would be discussed as a case study in order to show the potential of mesoscopic imaging for materials investigation in general. The discussion would include the inspection and diagnostics of flat panel display systems and the *in situ* investigation of the discoloration and degradation of Japanese pigments and colorants.

Results and Discussion

Flat Panel Display System

In this section, we demonstrate briefly show how to visualize the details of a large object such as a plasma display panel or liquid crystal display panel with the proposed system for full automatic measurement and defect detection of large surfaces. The mesoscope systems can be used as versatile tools for research and increase the automation and replace the quality control system of the production lines which is non-automatic (or at best partially automatic) at this moment. There were already some previous reports on the use of imaging for industrial in-line inspection. In previous studies, the focus was given to image processing algorithms [6-7]. In this paper, the focus is more on the acquisition of high quality images. There were some reports that proposed imaging set-up for industrial in-line inspection but they are of low quality and resolution [8-10]. The novelty of the technique being presented here is the ability to focus on mesoscopic details which is yet to be reported.

The flat panel displays were scanned using an ultrahigh-resolution scanner developed at Kyoto University. At high resolution, which in this case is at 1200 dpi, it is possible to see the sub-pixels of the display which constitute to the production of the images on the display. Figure 5 shows a typical scanned image of the display. It can be seen that sub-pixel arrays are clearly visible which can be used for evaluating its color values and use this information for inspecting the displays. One pixel on the display is composed of constituent R, G, B sub-pixels. The colors on the display are rendered by additive color mixing of the sub-pixels. An enlarged sub-pixel can be viewed by zooming in the scanned image of a blank white page from 200 to 800 percent of the original image size.

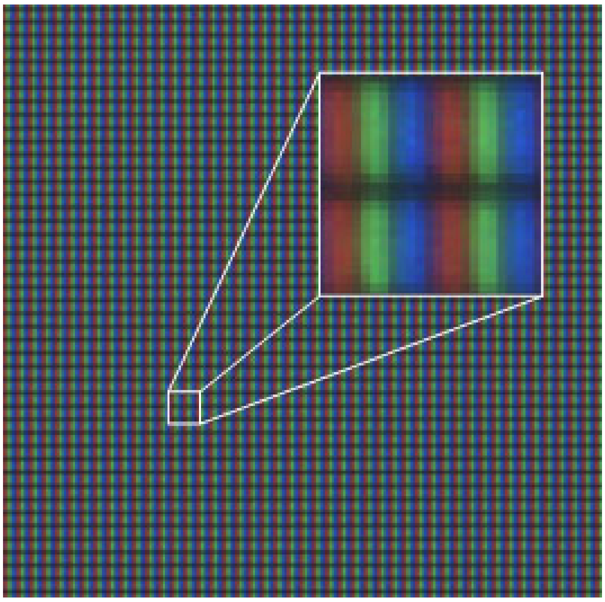


Figure 5. The figure shows a typical pixel representation of a display device

The high-resolution scans could also be used to detect physical defects on the surface of the displays such as scratches and other physical abnormalities. An example of which is depicted by Figure 6.

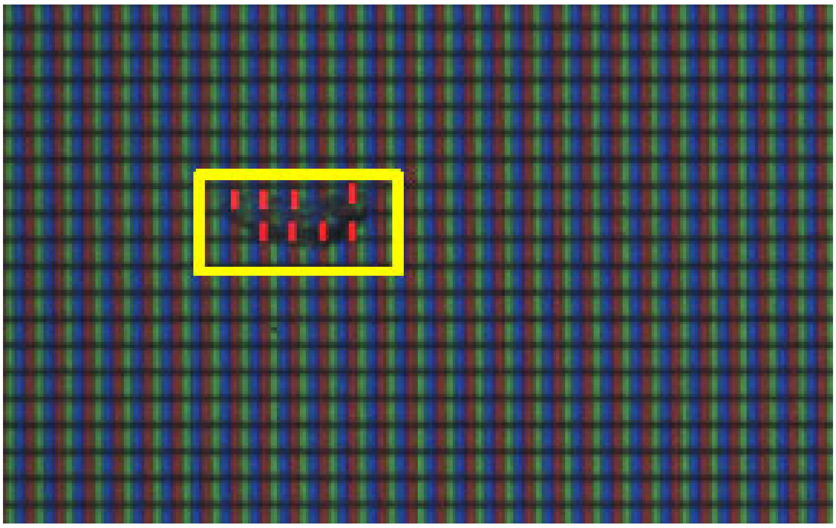


Figure 6. The area enclosed by the rectangular box shows physical damage on the surface of the display. This is normally unnoticeable using the naked eye but with the high-resolution scans this could be easily detected

In order to minimize the effect of viewing position, the display was moved and scanned multiple times to determine the range where the effect of the viewing angle would be negligible. This can be achieved if the normalized luminance has a flat profile. Combining the results of all the channels, the imaging range of viewing angle effects with negligible effects is between 55-85 mm range as shown in Figure 7.

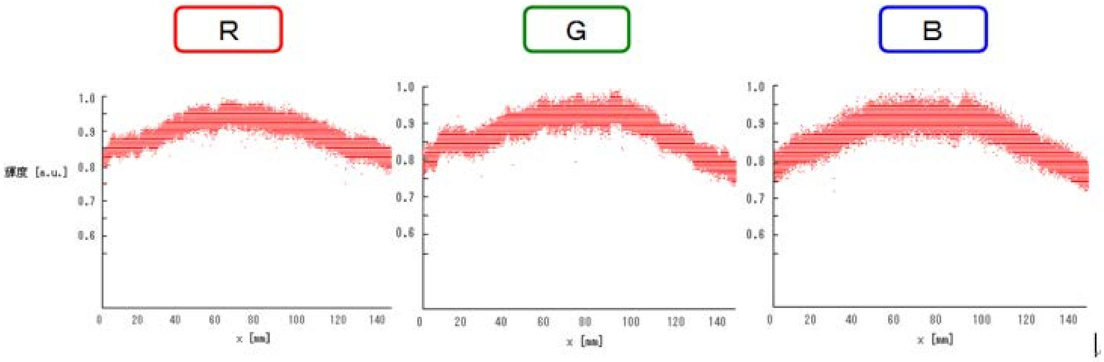
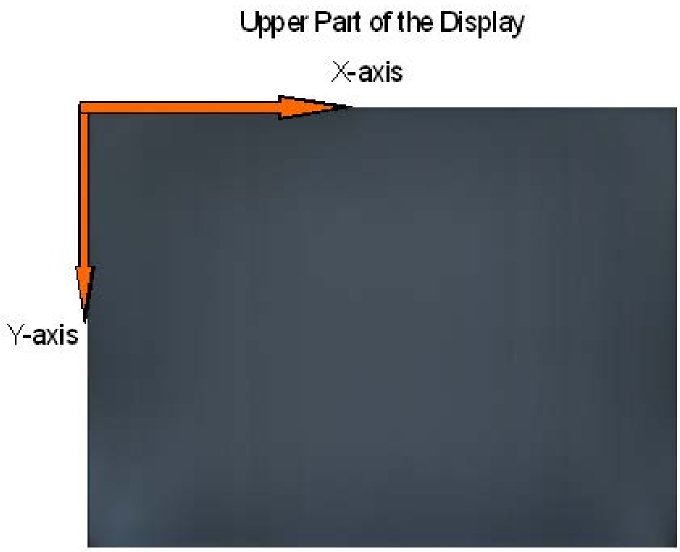
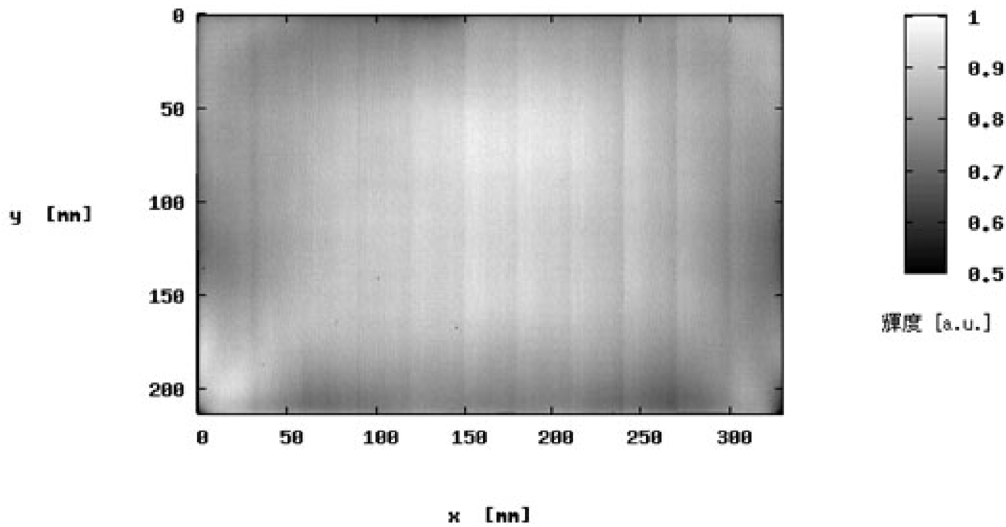


Figure 7. Effect of viewing position on the red, green and blue channels

After determining the effective scanning area and viewing angle, the scanned image of the display was processed. The intensity and brightness coming off the display was used to create an algorithm to evaluate display defects based on sub-pixel values. Figure 8 shows images of an unprocessed and a processed image using the developed algorithm. It could be observed that with the use of the technique employed in this study, dark spots and uneven luminance distribution are easily detectable. The figure shows high brightness near the center of the display while the brightness of the screen neat the edge was 70 to 80 percent.



(a)



(b)

Figure 8. (a) the figure shows the luminance of the display based on an unprocessed scanned image of a blank white page. (b) brightness of the display device based on sub-pixel values using the processing algorithm

In addition to the luminance of the sub-pixels, histogram extracted from the scanned images was also used to evaluate the display. Figure 9 shows four histogram representing different areas on the display. It could be observed that the three neighboring pixels have similar peak location but with different peak sharpness. For a perfect, defect-free display, the ideal histogram would have high and sharp peak value. As the peaks become broader and less pronounced, this could imply that sub-pixel is not working perfectly.

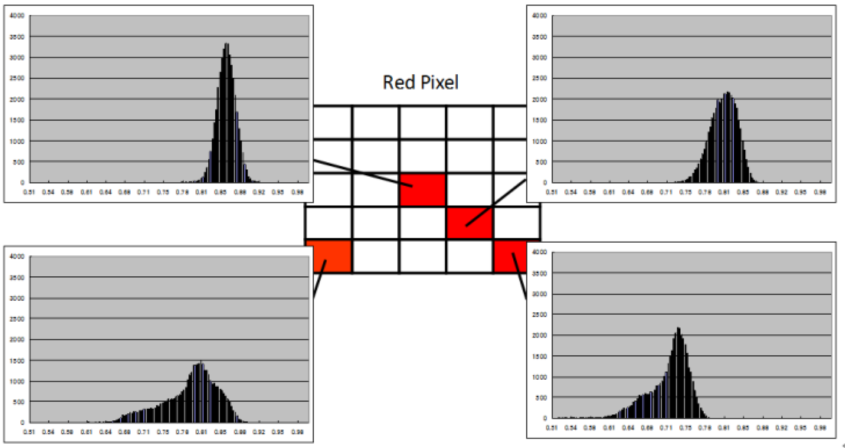


Figure 9. Histogram based on the sub pixel values extracted from the scanned images

In-situ Investigation of Color Degradation of Japanese Colorants

Degradation of colorants and pigments are important concern in many fields such as printing industry, paintings, and artworks, museums and cultural heritage [11-12]. Having a better understanding on the mechanisms involved could help in the development of new products, conservation and restoration of items with high values. Exposure to changing environments is one of the factors that contribute to degradation [13-17]. Among the elemental factors: external light sources, temperature and humidity are the most influential. Until now, knowledge about degradation is still limited and the mechanisms involved are still not well understood. Therefore, there is a need for further investigations on effect of different physical parameters on color degradation. In our recent work we used our mesoscopic systems to evaluate the variation of color as a result of external factors such as light source and temperature. In other recent projects, we used our super high resolution mesoscopes in developing new light sources using LED. The LED industry is growing extremely fast and the need to evaluate the light characteristics together with the after effects of the irradiation of light on delicate surfaces is increasing. This is especially true for Japanese colorants such as pigments and dyes.

In this study as a test case, azurite was chosen as the representative Japanese colorant. Azurite is a blue copper-based pigment. It is widely used in traditional Japanese paintings both in the ancient and modern times. The pigments were heated to a temperature of 300˚C for 80 minutes in air. Samples were acquired every 10 minutes until the time limit has been reached.

The heated pigments were characterized using reflectance spectroscopy, X-ray diffraction and X-ray fluorescence spectroscopy. Reflectance spectroscopy was used to investigate the changes in the spectral reflectance of the pigments while XRD was used to check the changes in crystallinity and structure as a result of heating. The reflectance spectroscopy was based on multispectral images captured with the proposed mesoscopic imaging system. Using a mathematical algorithm based on the Moore-Penrose pseuodoinverse method, the spectral reflectances of the pigments were reconstructed from the images. Finally, XRF using synchrotron radiation (SRXRF) was used to check the elemental composition of the pigments.

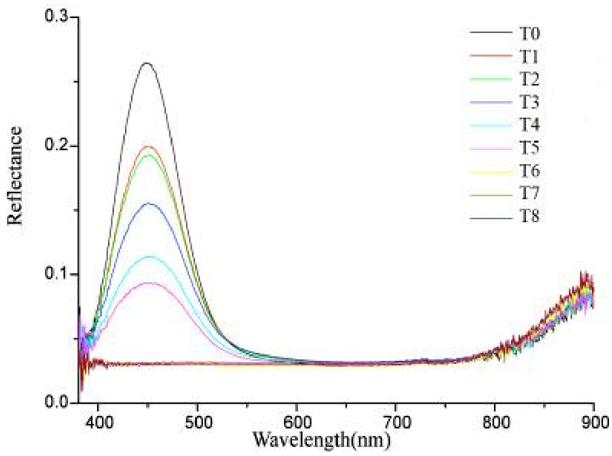


Figure 10. Spectral reflectance of the azurite pigments as function of time. *Note: T0-unheated; T1-10 minutes; T2-20 minutes…T8-80 minutes* [16]

As expected, the pigments were degraded upon subjecting them to high temperature. Significant changes in the spectral reflectance were observed even only after 10 minutes of heating. The spectral reflectance continued to decrease gradually up until 40 minutes of exposure then it drastically dropped afterwards. The changes are shown in Figure 10. The decrease in spectral reflectance is accompanied by the changes in pigment color. The pigments got darker until they were completely burned. On the other hand, the diffraction patterns of the heated pigments did not yield conclusive results compared to the reflectance spectroscopy results (Figure 11). Changes in the crystallinity were seen but no clear pattern was observed. Likewise, the SRXRF results did not yield results that could provide useable insights into the discoloration behavior of the pigments. The SRXRF spectra show the elemental composition of the pigments. It can be concluded from the result that the elemental composition is unaffected by the heating process. The SRXRF results are summarized in Figure 12.

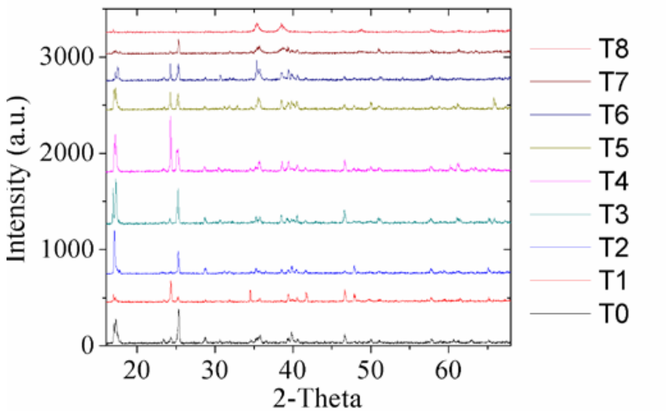


Figure 11. XRD of the azurite pigments as function of time. *Note: T0-unheated; T1-10 minutes; T2-20 minutes…T8-80 minutes* [16]

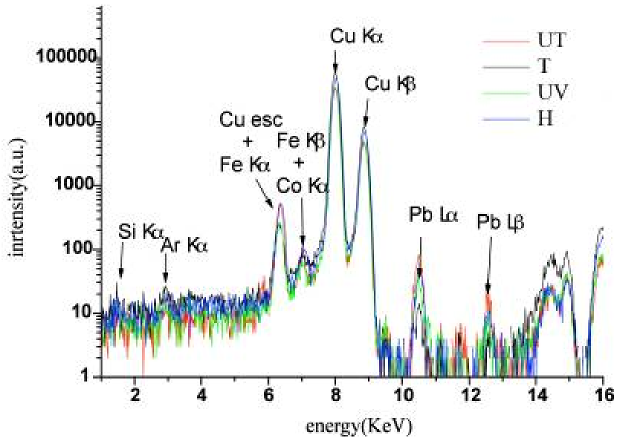


Figure 12. XRF spectra of the azurite pigments. The spectra remained unchanged even though the pigments were subjected to heat, humidity and ultraviolet radiation. *Note: UT-untreated; T-heated; UV-ultraviolet; H-humidity* [16]

In this part of our study, azurite pigment was selected as representative pigment for investigating the effect of heating at high temperature on discoloration. The motivation is to use the insights to better understand the degradation mechanism. This knowledge would be very useful in the investigation of cultural heritage paintings, which can aid preservation, conservation and restoration of precious heritage artifacts. Results have shown that among the characterization techniques used in this study, reflectance spectroscopic data provides the most useable information. Discoloration of the pigments was observed as a result of heating. On the other hand, both X-ray diffraction and X-ray fluorescence spectra provide inconclusive results to aid in better understanding the mechanism of pigment degradation.

Conclusions

Mesoscope is similar to an optical microscope in terms of bringing small dimensions which are not visible to the naked eye into dimensions showing accurate surface details. However, microscopes give high-resolution images of low focal distances and narrow field of vision. On the other hand, mesoscopes bring into sight the details in microscopic level of large objects that might even be in dimensions of a few meters. Therefore, mesoscopy can be used as a method for inspection of macroscopic and microscopic properties in industrial production lines. The system presented in this study has already been used in six different fields such as:

i) Color evaluation of LED and degradation of colorants
ii) Flat panel display panels inspection
iii) Inspection of medium-sized 3D industrial objects
iv) Imaging and conservation of cultural heritage
v) High resolution (10-20 micrometer level) spectrometry
vi) Imaging of biological samples (e.g. butterfly wings, bugs and insects)

With the continuous advancement in sensor and computing technologies, the potential application of mesoscopy could become ubiquitous in industrial inspection and diagnostics.

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