TESTING THE IMPACT OF LIGHT CONDITIONS ON IMAGE QUALITY FOR OPTICAL INSPECTION OF SURFACE DEFECTS

George Cordoyiannis, Iris Fink Grubačević, Tomaž Savšek

Abstract:
Contactless and automated optical inspection tools make headway in comparison to tactile methods in modern factories. In order to develop an advanced optical tool for inspection of metal components produced for the automotive industry, one faces a number of challenges. We hereby present a brief overview of the image quality of surface flaws and defects obtained under different light conditions. Lacquered metal components of simple and complex geometries have been illuminated by light of variable intensity. Certain trends have been revealed regarding the obtained image quality.

Keywords:
optical inspection, surface defects, illumination

1 Introduction

In the modern smart factories, automated contactless inspection methods continuously gain ground over human inspection (being subjective) and tactile methods (suffering from slow data acquisition and interpretation). Optical inspection can be applied at different stages, from the quality control of freshly produced components to the posterior check of the moving parts' wear [1]. Within the concept of Industry 4.0, not only do smart optical inspection tools collect images, but they also implement statistical process control and communicate with other devices in real-time. Their implementation in the production line detects flaws and defects, providing information about the quality and the uniformity of the manufacturing process in real-time. The harvested data can be further analyzed to enable predictive maintenance of the tool itself and reduce downtimes [2].

The quality of optical inspection is influenced by the specific and often harsh conditions met in an industrial environment, which may include variations in the illumination, contaminations and vibrations. Light conditions, in particular, are reported to have a remarkable impact on the captured image quality [1]. This impact can be quite complex in the vicinity of flaws and defects. For example, a smooth lacquered surface is specular and reflects at an equal and opposite angle to the incident light. However, regions that exhibit flaws, defects and variable roughness reflect at additional directions.

Research Fellow **George Cordoyiannis**, PhD, Senior Lecturer **Iris Fink-Grubačević**, MSc, both Faculty for Industrial Engineering Novo mesto; Assistant **Prof. Tomaž Savšek**, PhD, TPV Group d.o.o. & Faculty for Industrial Engineering Novo mesto

Depending on the industrial application, different wavelengths λ of light can be utilized. Ultraviolet light (100 nm < λ < 400 nm) is typically chosen for the inspection of glues, thin films and semiconductors. White or colored light across the visible spectrum (400 nm < λ < 750 nm) is often applied for metals and objects with multiple color surfaces that require high color rendering images. Furthermore, near and far infrared (750 nm < λ < 1 mm) is mostly chosen for optical inspection of semi-transparent materials and natural fibers, as well as for thermal imaging.

We hereby present a short overview of measurements, performed under different light conditions, in order to detect flaws and defects on the surfaces of lacquered metal components. These measurements aim to assist in choosing the optimal light conditions for reduced surface reflectance and enhanced image clarity, addressing one – out of many – challenges related to the development of an advanced optical inspection tool EAGLE. The design of this tool is customized for the inspection of metal components produced for the automotive industry [3].

2 Experimental setup and samples

Light emitting diode (LED) sources are reported as superior to other types of light sources for achieving an optimum defect expressivity on flat, cylindrical or complex geometry reflective metal surfaces [1, 4], such as the ones of our interest. Based on the above, a LED array source has been chosen to illuminate the components. It produces warm-white light with a correlated color temperature of 3000 K. Our measurements have been planned and performed by means of a simple, house-in-built setup in order to test the impact of light conditions on the captured image quality around defects. This setup consists of the following parts: (a) a Nikon digital camera equipped with Tamron 90 mm f/2.8 Di Macro Lens, connected to a laptop for a direct viewing of the captured images (b) a Cree X-Lamp CA2550 LED array source (Cree EasyWhite® LEDs, uniform chromaticity profile), driven by an external amplifier - intensity controller, (c) tripods that offer a stable placement and a three-dimensional movement of the camera, LED source and inspected component. This setup serves as a simple approximation of the more sophisticated EAGLE optical tool, where a robotic arm would be used to collect the components from a moving conveyor and place them properly with respect to the camera and the light source.

Cylindrical or complex geometry metal components bearing defects have been provided by TPV Group d.o.o. Measurements have been performed for vertical and oblique placements of the camera and the LED source with respect to the surface defects. Images with a resolution of 3696 x 2448 pixels have been captured under different ambient conditions, such as in a dark room (henceforth referred to as "dark ambient") and in a candent room with Neon light from the ceiling (henceforth referred to as "bright ambient"). In these dark or bright ambient conditions, the inspected components have been illuminated by LED light of variable intensity, in the range from 50 lm to 2000 lm. The intensity has been derived by accurately measuring the source driving current and then referring to the luminous flux-current chart on steady-state operation. The distance between the LED source and the components has been set to 20 cm and 10 cm when observing defects on the outer and inner surfaces, respectively.

3 Results and Discussion

Images of defects on black-lacquered external surfaces of a cylindrically-shaped metal component have been captured under different light conditions. The presence of low intensity LED improves the image quality obtained in dark ambient. The impact of variable LED illumination on the probed defect morphology is depicted in *Figure 1*. The two images are obtained by illumination intensities differing by an order of magnitude, 100 lm and 1000 lm, respectively. For 100 lm, a sharper and more detailed image is obtained, in comparison to the 1000 lm. In general, images above 500 lm suffer from increased surface reflectance. Further increase of the intensity up to 2000 lm, degrades the image quality derived in both dark and light ambient conditions. In the case of a bright ambient, the effect of low intensity LED is milder, whereas a high intensity produces once again strong reflections. These trends have been steadily reproducible for other similar defects on black-lacquered surfaces.

Defects on the surface of components with a more complex geometry have been also observed. The LED source and the camera have been placed either vertically above the inspected area or at oblique positions. Optimum results have been obtained for camera and LED source as close as possible to the vertical position above the inspected area. Representative images captured in a dark or a bright ambient, as well as their combination with low intensity LED are shown in *Figure 2*. This com-

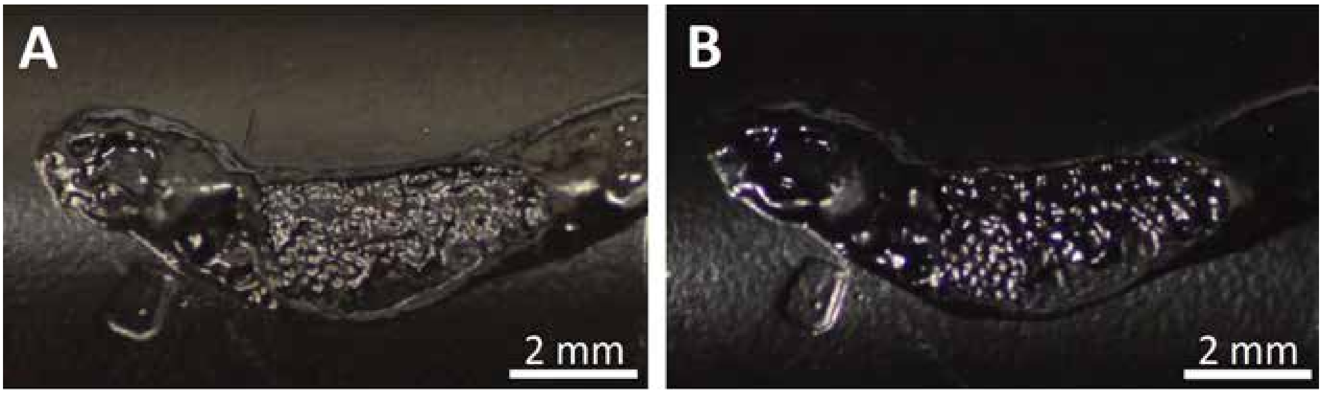

Figure 1 : *The image of a defect on the external surface of a lacquered metal cylindrical object is obtained in: dark ambient + LED illumination of 100 lm (panel A); dark ambient + LED illumination of 1000 lm (panel B). The 100 lm image is characterized by reduced reflections and enhanced details of the defect morphology.*

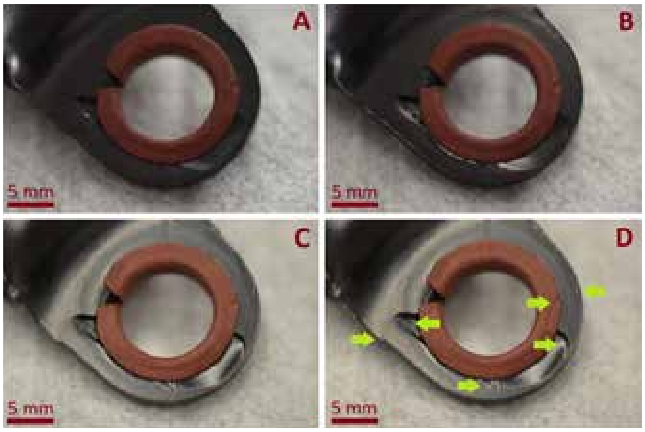

Figure 2 : *Images of a complex geometry component obtained in: dark ambient (panel A); dark ambient + LED illumination of 100 lm (panel B); bright ambient (panel C); bright ambient + LED illumination of 100 lm (panel D). The green arrows (panel D) mark the different types of flaws and defects: small cavities, bulges, grooves and increased surface roughness.*

ponent consists of a black-lacquered metal part with an attached non-polished and less reflective ring. It bears defects in the form of small cavities, grooves, bulges, as well as increased surface roughness towards the edges, which are marked by green arrows in one of the panels of Figure 2.

In the case of a dark ambient, the LED illumination highlights minor defects and reveals the surface roughness, which is hardly visible otherwise. Simultaneously, it weakly increases the reflectance, which does not degrade the image quality up to 200 lm. Higher intensities, in the range from 500 lm to 2000 lm, are accompanied by a significantly increased reflectance. In the case of a bright ambient, the image clarity exhibits only a minor improvement due to LED illumination, mostly in revealing the surface roughness. The three-dimensional shape of small cavities and grooves is better distinguished in the case of a bright ambient compared to a dark one. Regarding the placement of the camera and LED source, the results are of reasonably good quality for angles up to 30° with respect to the inspected surface. In some cases, the tiny bulges are better visible in case of strong illumination; however, the increased reflections degrade the overall image quality.

The detection of defects on the internal surfaces of cylindrically-shaped components is more challenging. In this case, the inspected component has been attached on a clamp (simulating the robotic arm in the configuration of EAGLE tool) between the camera and the LED source that are facing each other as schematically depicted in *Figure 3*. There exist no essential differences between images obtained with and without low intensity LED in a bright ambient, as it can be seen in the panels of Figure 3 (note that a dark ambient did not produce any good images in this case). Apart from a parallel position with respect to the object's cylindrical axis, the camera has been also placed at small inclinations (from 2° to 8°) in an effort to better highlight the surface morphology of specific defects. However, the inclined camera placement did not offer any remarkable improvement. Contrary to the case of defects on the external surfaces, in the case of internal surfaces the LED illumination did not show any visible effects.

The aforementioned trends, as revealed in Figures 1, 2 and 3, have been fully reproducible for several types and sizes of defects on different components. Although only representative examples have been presented, the overall trends are supported by a large number of measurements, thus, they are robust. The robotic arm seen in Figure 3 is used to select one every few components, as they move along the conveyor, and perform a sampling inspection. Via this end-of-line testing, the EAGLE smart optical tool performs a pass-or-fail check and places the component back to the conveyor or disposes of it in case it is faulty [3]. At the same time, it can send feedback about faulty components to the production line, preventing downtimes and increased costs. However, it is worth noting that the implementation of an optical inspection tool near the production line requires the dumping of vibrations originating from the adjacent industrial machinery.

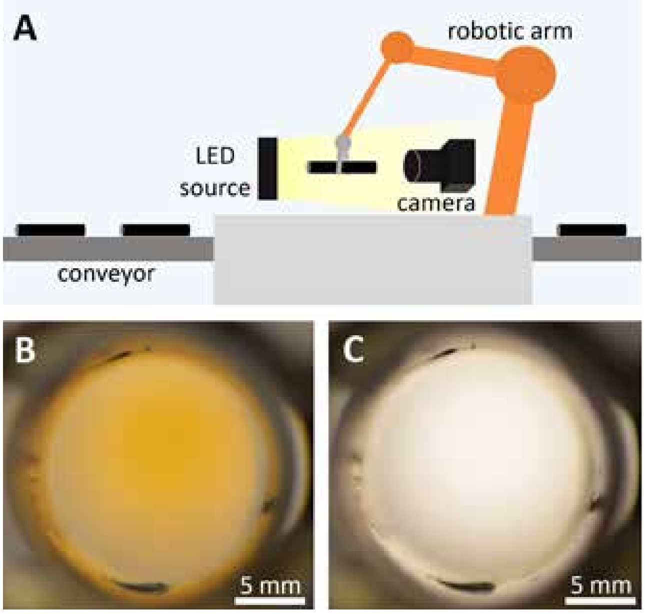

Figure 3 : *The configuration of the camera and light source for capturing images of defects on the inner surfaces is depicted (panel A). The presented images have been captured in: bright ambient (panel B); bright ambient + LED of 100 lm (panel C).*

4 Conclusions

Flaws and defects on metallic surfaces have been observed under different light conditions by means of a simple, house-in-built setup. The image clarity has been evaluated for different conditions, in a dark or bright ambient, as well as with and without LED illumination. Certain trends have been revealed that could be summarized as follows. First, LED illumination of low intensity (100-200 lm) is beneficial in the vast majority of cases; it yields sharp and detailed images of the defects' shape and morphology, accompanied by a weak and non-disturbing reflectance. Second, higher intensity LED illumination (500-2000 lm) is apparently beneficial for capturing the shape of tiny bulges; however, it persistently causes strong light reflections from the lacquered surfaces and downgrades the overall image quality. Third, the shape and morphology of defects is effectively captured by camera angles up to 30° with respect to the inspected surface. Fourth, in the particular case of defects on the inner surfaces, LED illumination at an angle of 180° with respect to the camera did not offer any improvement of the image quality.

The presented measurements have been performed aiming to assist the design of a non-contact optical tool EAGLE for inspection of metal components that are produced for the automotive industry. For the latter, dimensionally-stable and defect-free components are of major importance. Car spare parts must fit tightly and prevent any type of mismatch and malfunction, leakage of oil, intake of moisture and development of rust, as well as disturbing squeaking and rattling noises [5]. At the same time, the detection of defective components via a selective inspection of components along a moving conveyer can give feedback to the production line at an early stage, thus, reducing downtimes and costs.

Sources

[1] Ramzi, R., Bakar, E.A.: Optical wear inspection of countersink drill bit for drilling operation in aircraft manufacturing and assembly industry: a method, IOP Conference Series: Materials Science and Engineering 370/2018, pp.: 012041(1-8).

[2] Noureddine, R., Solvang, W.D., Johannessen, E., Yu, H.: Proactive learning for intelligent maintenance in Industry 4.0, Advanced Manufacturing and Automation IX, pp.: 250-257 (Springer Singapore, 2020).

[3] Petrič, A., Kurbegović, H., Savšek, T.: Quality challenges and state of the art in designing development requirements for the system EAGLE, 6. International Conference on the Development of Industrial Engineering: Opportunities, Potentials, Challenges, Novo mesto, 2021.

[4] Li, L., Wang, Z., Pei, F., Wang, X.: Improved illumination for vision-based defect inspection of highly reflective metal surface, Chinese Optics Letters 11/2013/2, pp.: 021102(1-4).

[5] Bogue, R.: Car manufacturer uses novel laser scanner to reduce time to production, Assembly Automation 28/2008/2, pp.: 113-114.

Preizkušanje vpliva svetlobnih pogojev na kakovost slike za optični pregled površinskih napak

Razširjen povzetek:

Razvoj brezkontaktnih in avtomatiziranih orodij za optični pregled predmetov napreduje v primerjavi s taktilnimi metodami v sodobnih tovarnah. Da bi razvili napredno optično orodje za pregledovanje kovinskih komponent, se soočamo s številnimi izzivi, med njimi tudi z izbiro optimalnih svetlobnih pogojev. Predstavljamo kratek pregled meritev kakovosti slike površinskih napak in defektov, pridobljenih pri različnih svetlobnih pogojih. Namen izvedenih meritev je pomoč pri razvoju orodja za optične preglede EAGLE, ki se uporablja za pregled kovinskih komponent proizvedenih za avtomobilsko industrijo. Meritve pomagajo pri izbiri optimalnih svetlobnih pogojev za zmanjšano površinsko odbojnost in večjo ostrost slik.
Preprosto ali kompleksno oblikovane lakirane kovinske komponente so bile osvetljene z LED-svetlobo spremenljive jakosti. V kakovosti slike se opazijo določeni trendi. Kar se tiče napak na zunanjih površinah, je LED-osvetlitev nizke intenzivnosti v veliki večini primerov koristna; daje ostre in podrobne slike oblike in morfologije napak, ki jih spremlja šibka in nemoteča odbojnost. V primeru napak na notranjih površinah LED-osvetlitev ni prinesla nobenih izboljšanih rezultatov.

Ključne besede:

optični pregled, površinske napake, osvetlitev

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