Perspectives in Science (2016) 7, 109—113

ScienceDirect
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New strategies for measuring and sorting shaped glass stones using image processing☆

Michal Kelnar*, Radek Martinek, Petr Bilik, Filip Volny, Jan Vanus, Zdenek Machacek, Jan Zidek

Department of Cybernetics and Biomedical Engineering, VSB — Technical University of Ostrava, 17. listopadu 2172/15, Ostrava-Poruba 708 00, Czech Republic

Received 26 October 2015; accepted 11 November 2015
Available online 17 December 2015

KEYWORDS
Image processing;
Shaped glass stones;
Machine vision;
Automation technology

Summary This article aims to propose progressive methods for objectively evaluating significant mechanical and geometrical characteristics of gemstones used for making fashion jewellery. These characteristics significantly affect the overall visual aesthetic look of the respective jewellery stones. Different image processing methods are used in industrial microscopy to design new products. The key aspects for having a successful design is thoroughly analysing the material for possible gem-stone defects and properly defining their behaviour when using different optical systems. Using a high-tech experimental laboratory, the authors carried out a control measurement. The main contribution of this paper is the design, implementation and verification of the functionality of new methods for evaluating the quality of machine cut jewellery stones. These progressive methods have the potential to succeed in industrial microscopy or defectoscopy.

Introduction

Machine cut jewellery stones and fashion jewellery stones (hereinafter SGS) are geometric spatial formations bordered by several ground surfaces. Their main function is primarily optical-aesthetic. The basic characteristics of aesthetic perception are brilliance, fire and sparkle; see Garcia-Ayuso et al. (2002), Jamal and Goode (2001).

Identifying and evaluating the parameters of a given SGS optical-aesthetic function is a subjective task and is difficult to quantify, thus it is very difficult for machines to perform this task. However, because assessments of brilliance, fire and sparkle are based on the translucency of the SGS, it is obvious that geometrical and mechanical characteristics of the given SGS significantly affect its resulting optical-aesthetic perception.

☆ This article is part of a special issue entitled ''Proceedings of the 1st Czech-China Scientific Conference 2015''.

* Corresponding author.
E-mail address: michal.kelnar@vsb.cz (M. Kelnar).

http://dx.doi.org/10.1016/j.pisc.2015.11.018

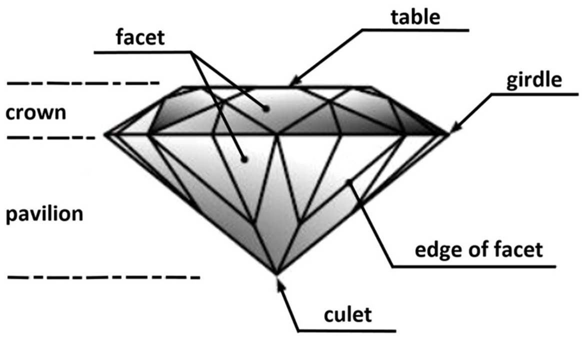

Figure 1 Parts of jewellery stone.

This article is focused on the use of modern defectoscopy methods, see Bovik (2010), Davies (2004), Rosenfeld (2013), Sonka et al. (2014) to detect and evaluate (see adaptive methods in Martinek et al., 2010; Martinek and Zidek, 2010, 2014; Pavlidis, 2012) SGS defects. This especially applies to defects in geometry, surface micro-reliefs, integrity defects and defects found in the chemical silvering layer.

Methods

Ground SGS surfaces can be generally divided into functional faces that actively influence its optic effect, while optically non-functional faces do not significantly affect the final optical effect. SGS is geometrically divided into two parts — the crown and the pavilion, see Fig. 1, Jamal and Goode (2001).

The crown is the part of the stone that can be seen during normal use of the stone. The pavilion, on the other hand, is the part that normally cannot be seen. Faces that create the crown and the pavilion are optically functional. These two geometrical parts of the stone meet at a point called the girdle.

The girdle is an optically non-functional surface that is located around the stone's greatest perimeter. The girdle is the primary structural element of the stone that most significantly affects its geometrical dimensions.

The crown of the stone consists of three different shapes: facets, tables and edges. The facet is a flat face that is optically functional. There are always some located on a stone and their number depends on how the stone is ground. The table is also a flat optically functional face, however, there is only one of the on each stone. The plane of the table is parallel to plane of the girdle. Last, but an equally significant part of the crown, is the edges. There are several types of edges, but generally in ground stones, they are the lines or curves at which the facets meet the table and the girdle. Edges are divided into facet edges, table edges and girdle edges. A facet edge is the meeting point of two facets. A table edge is the meeting point of the facet and the table and a girdle edge is the point at which the facet meets the girdle. The pavilion of the stone also consists of three shapes. Facets and edges are the same, but instead of a table, there is a tip. It is the point where three or more facets meet. It is also the functional end-point of the stone, see Jamal and Goode (2001).

Current evaluation methods

a) *Evaluation using a reflective sphere* — this is an indirect method of evaluation. This method is based upon shooting a beam of white or monochromatic light perpendicularly through the table of the respective SGS. Inside the stone, the light spreads into beams which exit the stone and are reflected on a hemi-spherical focusing screen. The resulting image provides information about the stone's geometric characteristics, facet macro relief and correct structure, see Garcia-Ayuso et al. (2002), Jamal and Goode (2001).

b) *A profile projector* — this is used to measure the product's basic geometric ratios. It is also an indirect method of evaluation. A profile projector is a device that reflects a highly magnified shadow on the focusing screen. This shadow is then used for taking general measurements of geometric characteristics (lengths, angles) that cannot be measured directly on the stones due to their small size, see Garcia-Ayuso et al. (2002), Jamal and Goode (2001).

c) *A contact profilometer* — this is a device used to measure facet relief up to a defect depth of 0.1 μm. The device operates as follows: A diamond tip moves across the surface of the facet. When the tip moves over a bump, it results in a vertical movement that is then recorded. The result is a parameter that represents the roughness of the respective surface. This measurement method is, however, not entirely accurate, see Garcia-Ayuso et al. (2002), Jamal and Goode (2001).

d) *Interference of light waves* — these waves are in a different phase due to their reflection from the different height of points in the surface of the stone. It is a very sensitive method used to measure the geometric characteristics of a surface at nanoscale. Due to the nature of the product, it is also necessary to perform a visual inspection. The first type of inspection is the ''visual evaluation by the human eye''. Such inspection is performed on products laid over screens or on products that are equally oriented. A comparison with a reference sample is often used. For such assessment, it is necessary to provide a light source which provides light which's spectral characteristic is as close as possible to natural daylight and more importantly to the eye of a trained and experienced evaluator. All optical-aesthetic characteristics and defects that can be identified by eye are visually evaluated. ''Visual evaluation by magnifying glass'' is performed at 4× to 20× magnification. This method is mostly used to inspect the surface of the product, the grinding quality and the inner purity of the stone. Commonly used are gem magnifying glasses, Brinnel magnifiers or table magnifiers, see Garcia-Ayuso et al. (2002), Jamal and Goode (2001).

e) *Visual evaluation by a microscope* — when a detailed assessment of presence of various artefacts inside a product is needed, the ''visual evaluation by a microscope'' is used. The microscope operates at 20× to 500× magnification and is used to identify and distinguish defects on the surface of the product or in-side it. The microscopic image can be digitalised and processed by a computer (Sanz, 2012; Snyder and Qi, 2010; Sonka et al., 2014;

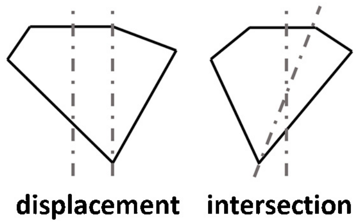

Figure 2 Axes alignment.

Steger et al., 2008; Vlach and Kolar, 2012). This idea then gave birth to my assignment.

Defects

Defects can be divided into several groups. The first group are geometric defects. In these defects, the stone is unbalanced at first sight. Such stones are called ''crooked'' or ''misaligned''. These defect occur when the stone axes are mutually displaced or intersected, see Fig. 2.

Second group are micro relief defects of grinded and polished faces. These imperfections are defects on the face of a grinded facet, which, in ideal conditions, should be perfectly smooth. The size of these defects varies from tenths to tens of micrometres. Qualitative requirement is that these defects occupy a maximum of 0.5% of the total area of a facet. This criterion applies only when the defects are not concentrated in one place.

Third group are defects of the product's integrity. These defects are solely mechanical and occur mostly when manipulating the products. It is not only a defect of a certain area, but of the stone as a whole.

The last group of defects are defects of the chemical silvering layer. It is a thin metal layer on the bottom of the stone which increases light reflectance inside the stone due to its insufficient refractive index. Should this layer be damaged, the light would pass through the stone and the product would not meet the desired optical-aesthetical parameters. First the stone is machined and then the layer gets stretched on it. Several possible defects can consequently occur. Mostly, it is an unfinished, overdone or a damaged layer.

Experiments

Area scan camera

Due to the nature of the task solved and by comparing the parameters of the available cameras, ACA 2500-14gm Basler camera was used for implementation. It is a monochromatic area scan camera with a resolution of 2592×1944 pixel, CMOS sensor size 5.70 mm $\times$ 4.28 mm, 12-but AD converter with a frame rate of 14 fps.

A MC100$\times$ macro lens has been selected for the initial tests. A SGS size less than 3 mm is assumed which is the size of the field of view of the macro lens.

The last step was the selection of lighting. Testing several types of lightning (bright field, dark field, light with both narrow and wide angle, etc.) proved the white circular light bright field from CCS (mode LDR2-50SW) to be the most suitable for a single stone. Resulting images are shown in Fig. 3.

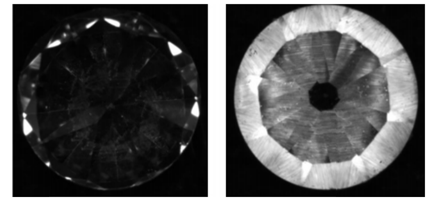

Figure 3 Macro lens.

The next phase focuses on capturing several stones placed in a 5×5 matrix. The circular light used in the previous experiment could not light up the whole area evenly. Stones placed closer to the centre were lit up sufficiently but stone closer to the edge were less illuminated from one side, see Fig. 4.

A variant with an area scan camera and a given lighting is usable, but only in the case of simultaneous check of a small amount of stones.

Line scan camera

A completely new optic system had to be designed for the use of the line scan camera. Furthermore, it was necessary to ensure a constant travel speed. Such travel along with a control system is supplied by Preciosa (Jamal and Goode, 2001).

A Basler L802k line scan camera with the resolution of 8160 pixel and pixel size of $5 \times 5\,\mu$m was used. The optical system is also equipped with the T16M36 telecentric lens by OptoEngineering. In combination with the selected camera, the length of the field of view is 41 mm. The last component of the optical system is a light source, Effi-Flex_20_000 with a beam angle of 10° by Effiflux. This is not a typical line lightning, however, due to the structure and homogeneity of the emitted light, this light source is suitable for the use with a line scan camera.

In order to illuminate the entire scanned line homogenously, two light sources are used, each on opposite sides of the camera. Due to the shape of the stones, it is best

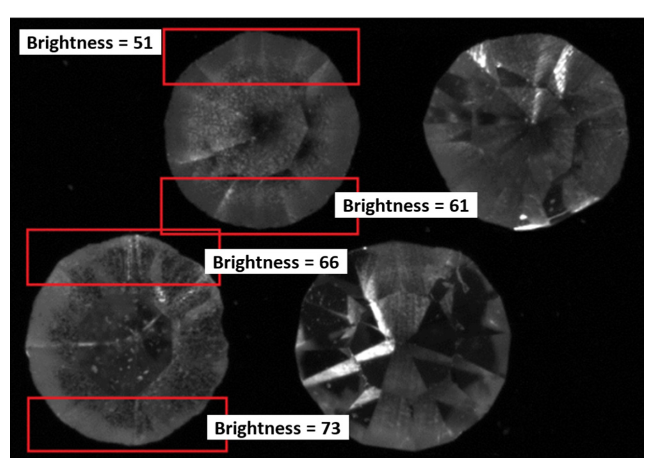

Figure 4 Sample diminished light towards the upper end of the image.

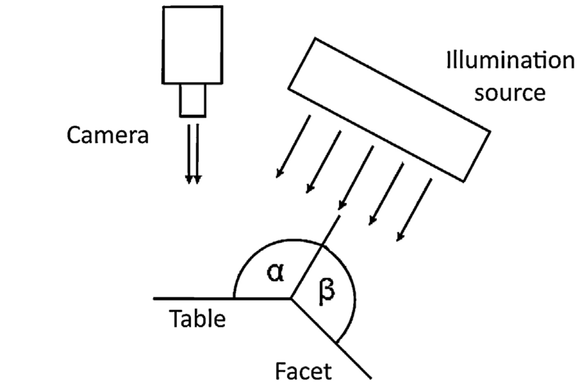

Figure 5 Lighting angle towards the camera and the object.

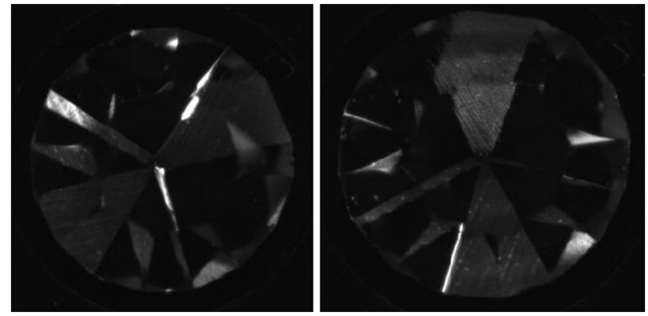

Figure 7 Illustration of the effect of stone rotation on unwanted reflections.

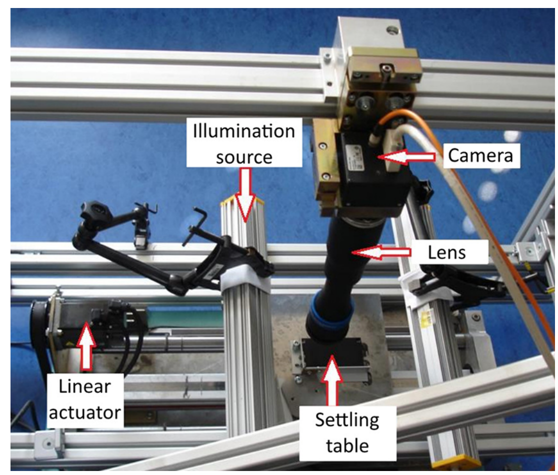

Figure 8 The resulting tester station.

to target the light between the table and the facet, see Figs. 4 and 8.

Should the angle α be smaller, the light would reflect from the table directly into the camera. Should conversely the β angle be decreased, the light would reflect into the camera from the facets. By shooting the light on the edge of the stone, the light does not reflect from the faces of the stone's crown into the camera and thus the camera is able to capture the internal geometry of the stone (Fig. 5).

Results

Thanks to the experiments, it turned out that two line lights are not sufficient in all cases. If the jewellery stone contains an internal defect, the current lighting is suitable. However, if the defect occurs on the surface of the stone (mostly defects of chemical silvering layer — and overdone or reverse layer), the stone is not homogenously illuminated from all sides. It is therefore necessary to continue to select a suitable lightning. Other findings that the experiments brought concern the distance of the lights from the object and the angle of the emitting light. The distance of the lights from the object is not too significant, provided the intensity of the light is sufficient. Selecting the best angle at which the light shines on the stones is also very significant aspect to ensure a high quality of capturing the geometrical and mechanical characteristics of the SGS.

An interesting phenomenon of lit girdle occurred when analysing the stones, see Fig. 6. It tuned out that this is a manufacturing defect which is not visible to the human eye even under microscope. It is therefore possible to classify such stones as good. This artefact, however, on first sight indicates the similar characteristics to the defect of an ''overdone layer'', see Fig. 6. To distinguish a good stone from defective it is therefore necessary to focus not only on intensity but also on the structure of the lit area. As shown in Fig. 6, the lit girdle has a smooth structure, whereas the overdone silvering layer has not. This can be used to distinguish these two jewellery stone defects.

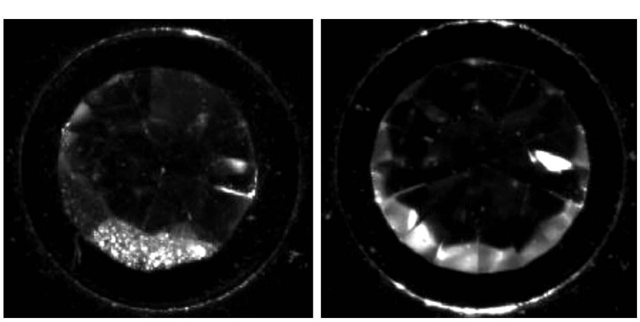

Figure 6 Sample diminished light towards the upper end of the image.

Another problem appears to be the big influence of the stone rotation around its axis on the presence of unwanted reflection on the facet edges. Experiments showed that the same stone in one position contains unwanted reflection, but when rotated just by several tens of degrees, the reflection disappears, see Fig. 7.

Conclusion

Though line scan cameras are commonly used in machine vision, an application that would deal with a similar problem that this article describes has not yet appeared. Newer types of cameras offer higher line resolution and also higher line frequency nowadays. That means that the scanned object can move faster under the camera and by selecting a larger lens, it is then possible for the camera to capture much wider field of view while maintaining the desired number of pixels per stone. However, the higher the camera resolution, the

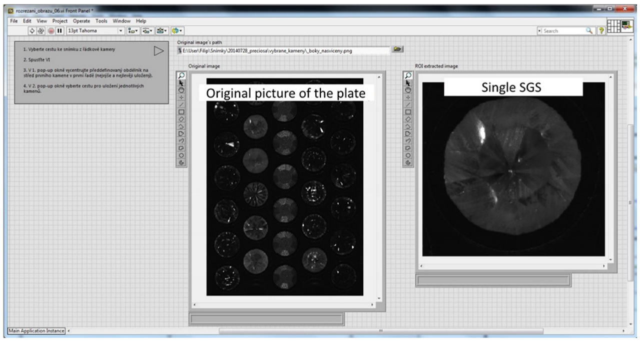

Figure 9 Demonstration of the front panel developed applications.

smaller the individual pixels are and thus their sensitivity decreases. For example, a camera with the resolution of 4080 px has pixels in the size of 7 μm, but the L802k model with the resolution of 8160 px has pixels wide only 5 μm. The useful area of the light-sensitive cell is thus almost two times smaller and it is therefore necessary to provide much more light.

The main contribution of this article is the proposal, implementation and verification of the functionality of new methods for objective evaluation of the quality of machine cut jewellery stones. These progressive methods have the potential to succeed in industrial defectoscopy.

The practical measurements revealed that the results achieved by measuring systems based on virtual instrumentation are very satisfactory. Virtual instrument differs primarily in the ability of the end user to define the core functionality of the instrument through software. Where a traditional instrument has vendor-defined embedded firmware, a virtual instrument has open software defined by the user. In this way, the virtual instrument can be reconfigured for a variety of different tasks or completely redefined when an application's needs change, see Fig. 9.

Conflict of interest

The authors declare that there is no conflict of interest.

Acknowledgements

This research was supported in part by VSB-Technical University Ostrava, FEECS under the project SGS registration number SP 2015/181, SP 2015/154.

References

Bovik, A.C., 2010. Handbook of Image and Video Processing. Academic Press.

Davies, E.R., 2004. Machine Vision: Theory, Algorithms, Practicalities. Elsevier.

Garcia-Ayuso, L., Amador-Hernaandez, J., Fernaandez-Romero, J., De Castro, M.L., 2002. Characterization of jewellery products by laser-induced breakdown spectroscopy. Anal. Chim. Acta 457 (2), 247—256.

Jamal, A., Goode, M., 2001. Consumers' product evaluation: a study of the primary evaluative criteria in the precious jewellery market in the UK. J. Consum. Behav. 1 (2), 140—155.

Martinek, R., Al-Wohaishi, M., Zidek, J., 2010. Software based exible measuring systems for analysis of digitally modulated systems. In: 9th IEEE Roedunet International Conference (RoEduNet), 2010, pp. 397—402.

Martinek, R., Zidek, J., 2010. Use of adaptive filtering for noise reduction on communications systems. In: International Conference on Applied Electronic (AE), 2010.

Martinek, R., Zidek, J., 2014. The real implementation of NLMS channel equalizer on the system of software defined radio. IETE J. Res. 60 (2), 183—193.

Pavlidis, T., 2012. Algorithms for Graphics and Image Processing. Springer Science & Business Media.

Rosenfeld, A., 2013. Multiresolution Image Processing and Analysis, vol. 12. Springer Science & Business Media.

Sanz, J.L., 2012. Advances in Machine Vision. Springer Science & Business Media.

Snyder, W.E., Qi, H., 2010. Machine Vision. Cambridge University Press.

Sonka, M., Hlavac, V., Boyle, R., 2014. Image Processing, Analysis, and Machine Vision. Cengage Learning.

Steger, C., Ulrich, M., Wiedemann, C., 2008. Machine Vision Algorithms and Applications. Qinghua University Publication 355, pp. 1—3.

Vlach, J., Kolar, M., 2012. Fuzzy methods and image fusion in a digital image processing. Adv. Electr. Electron. Eng. 10 (1), http://advances.utc.