# IMPACT OF DAMAGED SURFACE ON COHERENT FIBER OPTIC BUNDLE ON THE RESOLUTION OF THE IMAGES

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**Abstract:** This study investigates the effects of surface scratches resulting from manual polishing on the resolution of images formed by optical fiber bundle. Size controlled scratches were introduced to the bundle's surface, and images were collected while gradually increasing the scratch severity. The results show that while scratches reduce light transmission and contrast, the resolution is more affected by the object-fiber edges alignment than the polishment scratches.

**Keywords:** Coherent plastic optical fiber bundles; resolution; polishment.

# IMPACTO DE SUPERFÍCIE DANIFICADA EM FEIXE COERENTE DE FIBRA ÓTICA NA RESOLUÇÃO DAS IMAGENS

**Resumo:** Este estudo investiga os efeitos de arranhões superficiais resultantes do polimento manual na resolução de imagens formadas por feixe de fibras ópticas. Arranhões de tamanhos controlados foram introduzidos na superfície do feixe e imagens foram coletadas enquanto a gravidade dos arranhões era gradualmente aumentada. Os resultados mostram que enquanto os arranhões reduzem a transmissão de luz e o contraste, a resolução é mais afetada pelo alinhamento das bordas da fibra do objeto do que pelos arranhões de polimento.

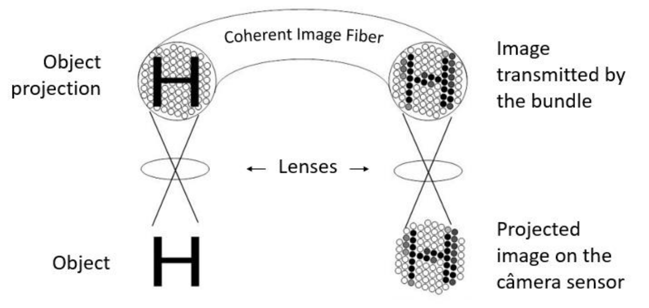
**Palavras-chave:** Guias coerentes de imagem de fibra óptica plástica; resolução; polimento.

## 1. INTRODUCTION

Coherent optical fiber bundles, also known as image guides, are a group of single optical fibers that transmit images from one point to the other, each fiber being similar, in function, with a pixel in a camera sensor. A large number of optical devices have been researched and developed for imaging purposes with coherent optical fiber bundles. Among these, endoscopes for medical uses and borescopes for industrial or military uses are the predominant ones. [1]

In this paper, a 2 mm diameter plastic optical fiber bundle with 7.400 fibers was selected as the main component. The plastic optical fibers that compose the coherent image fiber bundle are organized in a honeycomb pattern, the discrete fibers act as spatial sampling elements of the object. The finite fiber core diameter intensifies the inherent spatial quantization of the images and the potential loss of fine details. When the contours of the image projection may not entirely conform to a single fiber, a fraction of the object light projection is transmitted by the adjacent fibers, resulting on a color scale variation in the subsequent fibers of the transmitted image, as in Figure 1. [2].

Figure 1. Illustration of the transmission of image in a coherent optic fiber bundle. Adapted from [2]




Another effect inherent to fiber optic bundles is the light transmission loss. Considering Fresnel loss, cladding loss, interstitial spacing loss and manufacturing process loss, the maximum practical transmission efficiency of a fiber bundle is about 60% [3]. Properly polished faces in an image fiber bundle enhance light transmission, resulting in a brighter image. This reduces light loss by diffuse reflections on faces, leading to improved image clarity and contrast, closely related to sharpness and resolution [4]. Usually, for industrial uses, these items are already polished by the manufacturer, but otherwise they may be imperfect, impairing the process to which it was originally assigned.

The goal of this article is to discuss the image generated by non-commercially polished coherent plastic optical fiber bundles in two main perspectives: the impact of size-controlled sandpaper scratches on the surface face of the image guide and the characteristics of the coherent image fiber bundle that interfere in image sharpness.

## 2. METHODOLOGY

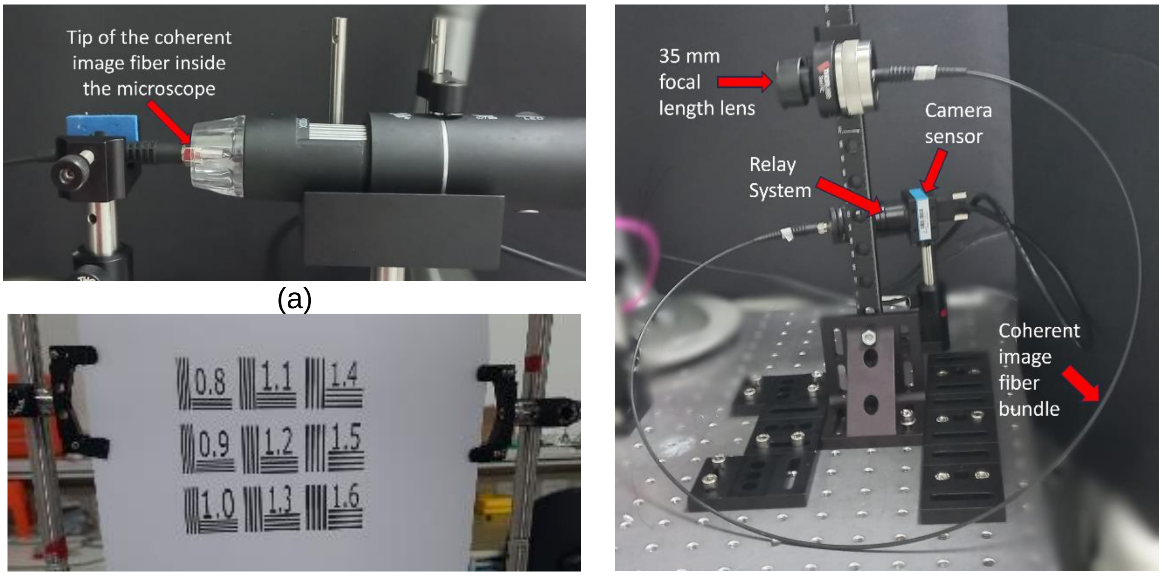
To realize the study on the coherent image fiber bundles, both faces were previously polished, one end face was preserved, and the other face was progressively roughened by following a sequence of sandpaper and polishing pastes scratches, that are shown in Table 1.

At the end of each scratch step, two images were captured. One of the scratched faces by a microscope, setup in Figure 2.a. and other of a printed target (Figure 2.b). A 35 mm focal length lens was coupled to the bundle on the observing side and a set of lenses on the other side forming a relay system to magnify the image to the camera sensor, setup in Figure 2.c. The printed target is like a NBS 1963 Resolution Test Target, but the numbers above the pattern indicate the width of each line, black or white, to simplify the analyzes. All the optical components are summarized in Table 2.

Table 1. Polishing sandpaper/paste grit and granule size correspondence [5]

| Sandpaper/ paste grit | Granule size |
|---|---|
| 12000 | 3 µm |
| 2000 | 10,3 µm |
| 1500 | 12,6 µm |
| 1000 | 18,3 µm |
| 600 | 25,8 µm |

Figure 2. Imaging capture setups. (a) Microscope setup with the optic fiber bundle, (b) Designed target, (c) Imaging setup to target images.




(a)
(b)
(c)

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The objective lens magnifies the object 0,016 times. Each singular fiber core of this fiber bundle measures about 19 μm in diameter, therefore, in the object plane, the smallest resolvable dimension would be about 1,18 mm, according to the Nyquist limit. [6]

Table 2. Components of the system.

| Component | Specifications | Supplier |
|---|---|---|
| Objective Lens | – Aperture f/2<br>– Focal length of 35 mm | #59-780 Thorlabs |
| Relay lens | - Aperture 1.12 and 3.2<br>- Focal length of 14 and 40 mm | #45-209 and #32-315 Thorlabs |
| Camera sensor | – 8,65 x 6,01 mm of sensor area<br>– 41 Megapixels<br>– Pixel size of 1,12 μm | DFK AFU420-CCS<br>Imaging Source |
| Coherent Image fiber bundle | – 7400 single fibers<br>– 0,5 of numerical aperture<br>– 2mm of active diameter | MCI-2000-24<br>Industrial Fiber Optics |

## 3. RESULTS AND DISCUSSION

The analysis of the images was separated into two subjects, one about scratches caused by sandpaper and polishing pastes and other about the arrangement of the bundle fibers inside the bundle, both with some impact on image quality.

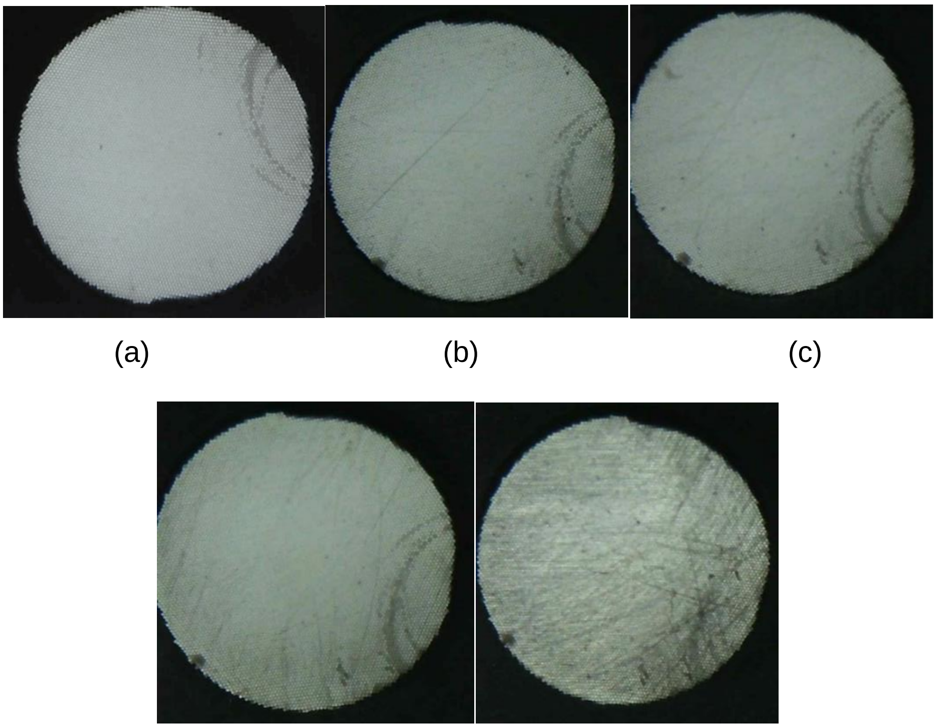
The lower number of the sandpaper, the bigger the granule size is, so a deeper scratch can be made. To the polishment procedure, the first sandpaper used should be the one with 25,8 μm granule size, it has the goal to get rid of the bigger imperfections of the surface, getting the face very scratched. The following sandpapers get rid of these consequence scratches until a very clean face, finished with the 3 μm granule size paste.

To achieve the objective of this analysis, the inverse sequence of scratches was performed, starting with the 10,3 μm scratches on a polished face (finished previously by a 3 μm granule size paste). In this way, there is certainty of the largest scratch width caused to the bundle for each step.

Figure 3 is a group of images showing the bundle face damaged by the sequence of sandpapers, and illustrates the procedure described before. The bundle being analyzed has an internal damage in the format of a semi-circle, not being affected by the superficial polishment.

The images show that as the surface is damaged with deeper and wider scratches, the image becomes darker. This is a consequence of the increase in diffuse light reflection on the scratched surface [6]. The surface with finer scratches presents more contrast and sharpness, which can be observed by the semicircular pattern of internally damaged fibers.

Figure 3. Scratches of the bundle's face seen on the microscope. a) finished with the 3 μm granule size paste, b) after the 10,3 μm granule size sandpaper, c) after the 12,6 μm granule size sandpaper, d) after the 18,3 μm granule size sandpaper, e) after the 25,8 μm granule size sandpaper



(a) (b) (c)

(d) (e)

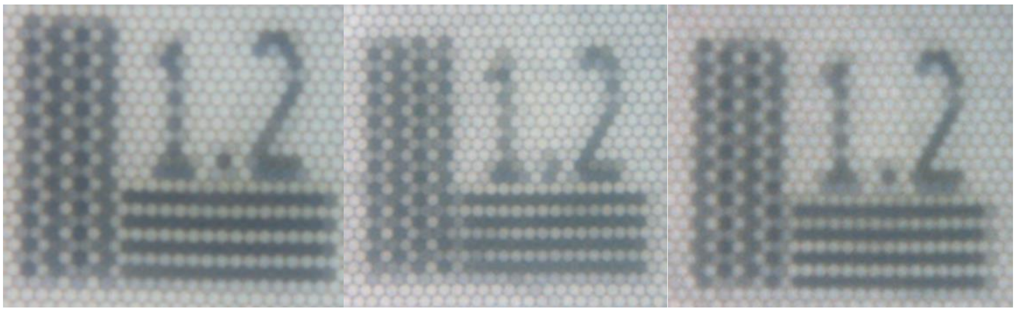
Figure 4 shows a cropped portion of the target image captured at each stage. The contrast difference between the completely polished surface (Figure 4.a) and the most damaged one (Figure 4.e.) is quite evident.

Although it is noticeable that the contrast is affected by the surface quality of the bundle, there is still enough contrast to resolve all the horizontal 1.2 mm dimensions, Nyquist's limit for the system [7].

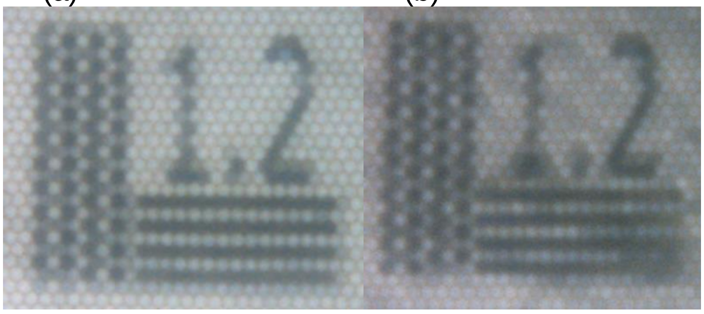
However, it is observed that the image resolution capacity is related to the alignment between the fiber pattern and the target. The vertical pattern of the target in the images of Figure 4. are not aligned in a way to keep the vertical lines of the targets parallel to the fiber rows of the bundle, causing partial transmission of color light in some fiber, as showed in Figure 1.

This misalignment can also be caused by internal deformations in the bundle. The graph in Figure 5, shows the gray scale of a line drawn along face of the bundle. The line was drawn to start and end in the interstitial space between the same two rows of fibers. However, the intensity variation of the peaks in the graph show that the line passed through rows of fibers, proving the deformation in the fiber organization pattern.

Figure 4. 1,2 mm pattern from the target image. a) finished with the 3 μm granule size paste, b) after the 10,3 μm granule size sandpaper, c) after the 12,6 μm granule size sandpaper, d) after the 18,3 μm granule size sandpaper, e) after the 25,8 μm granule size sandpaper.



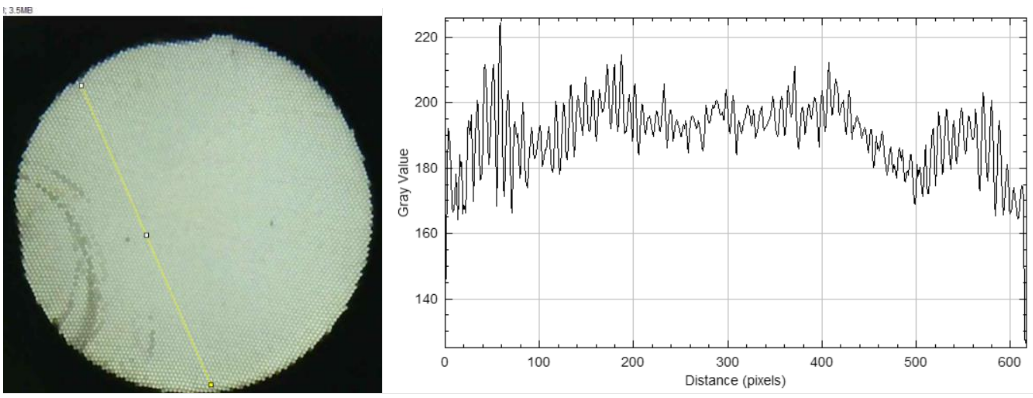
. (a) (b) (c)



. (d) (e)

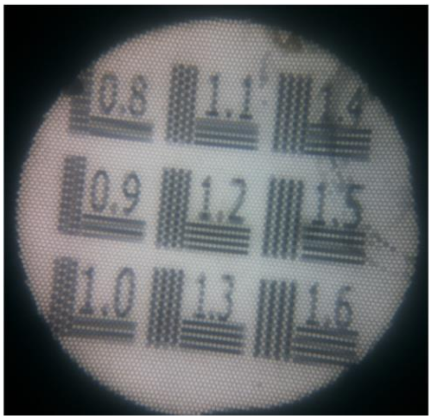
In the Figure 6, is possible to notice all the concepts cited before. The horizontal lines pattern with 1,2 mm width is fit with the row fiber (the fiber diameter is about 1,18 mm on the target plane) causing a good contrast image, but the vertical pattern is not fitted and so not resolvable. The larger width patterns have lines larger than a fiber diameter, but these patterns not fit an integer number of fibers on the width line, so there is a grayscale on the edges that spoil the contrast of the patterns at some point of the lines. It also shows the deformation on row direction, causing an irregular contrast on same line of the pattern.

Figure 5. Analysis of a diagonal of the face of the bundle. (a) Crossed lined image, (b) Line profile grayscale of the intensity of light.




(a) (b)

Figure 6. Target image by the polished coherent image fiber optical bundle




## 4. CONCLUSION

The images presented in the article showed the impact of scratches on the face of bundles upon the lighting and contrast of images formed by them. Although the scratches cause contrast degradation, this degradation isn't enough to damage the resolution, even to dimensions about Nyquist limit. For objects up to 1.6 mm and coherent image optical fiber bundles with 19 μm fibers, it was demonstrated that the misalignment between the fibers of the bundle and the object can impact the observed resolution more than scratches of 24 μm on the face of the bundle.

### Acknowledgments

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