



24th COBEM - 2017



24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-2000

COMPUTER VISION SYSTEM FOR THE EVALUATION OF LASER MARKING PROCESSING

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Abstract. *The LASER marking process is increasingly used in industry due to the growing demand for traceability of the produced components. The visual quality of these markings, which is very important for the effectiveness of their use in the productive sector, can be altered by different parameters such as the material of the workpiece, wavelength, pulse width, power distribution profile, power and frequency of the LASER source, among others. Therefore, it is important to develop tools and techniques to estimate the quality of the resulting markings, so that the relevant parameters for each recording can be correlated and controlled, as well as become easier to maintain the repeatability of the process. In this way, the present work presents the study and development of a tool that uses digital image processing techniques with the objective of qualitatively evaluating LASER markings. The results demonstrate the effectiveness of this tool, since they are like those obtained with commercial tools.*

Keywords: *Computational Vision, LASER Marking, Traceability*

1. INTRODUCTION

LASER direct marking is widely used as a flexible method of obtaining permanent marks containing traceability and identification information in Data Matrix and QR Code type codes (Velotti *et al.*, 2015). The LASER marking process is based on the interaction between energy and material by means of radiation (Poprawe, 2011).

This interaction can be manifested in three forms: mechanical (ablation of the material), thermo-physical (changes in the crystalline structure) or chemical (oxidation). These effects will depend on the material processed and the characteristics of the radiation, that is, the parameters of the LASER (Floresti, 2012).

The best marking results are obtained when there is an appropriate combination of LASER parameters, involving wavelength, pulse power, pulse energy duration, emission frequency, filling strategy, and velocity. To optimize the process and to obtain excellent quality, it is very important to know and analyze the marking quality criteria (Angelova, 2016; Trumpf, 2010).

A tool widely used in product and process inspection is computer vision, which employs images acquired by cameras and image processing algorithms in the analysis of characteristics of the inspected products (Steger *et al.*, 2008; Szeliski, 2010). The present work presents the development of a system for inspection by computer vision applied to verify quality characteristics of the LASER markings.

2. QUALITY ESTIMATION OF MARKING

2D code technology is based on the recognition of engraved patterns in cells and spaces or in a modular, marking matrix with defined dimensions. In this way it is important to have quality indicators for these 2D codes.

ISO IEC 15415 defines these quality indicators for two-dimensional codes. This standard presents such indicators that are relevant to a quality analysis of a two-dimensional code. These quality criteria are important references so that an image recording system can be adjusted with the aiming result that quality achieved is satisfactory (Tumpf,

2010; ISO IEC 15415, 2011). Among these indicators we can cite, contrast. In the case of LASER recording, the best marking results regarding contrast are achieved only when there is a well-defined combination of certain parameters, such as: pulse power, pulse energy, pulse duration, frequency and process speed.

The contrast K is determined by the difference between the background brightness (B_f) and the image brightness (B_i), divided by the background brightness (B_f) in percentage (Trumpf, 2010):

$$K = \frac{B_f - B_i}{B_f} \times 100\% \quad (1)$$

The markings have a certain border of contrast, which can be perceived. This contrast threshold is different when the marking is evaluated visually by human eyes and automatically by electronic devices. Scientific instruments, such as computer vision instruments, are designed to work as an optical sensor.

Many options for industrial sector-oriented computing tools are available in the marketplace, with features ranging from automated defect detection to manufacturing control and traceability. These tools are usually made up of software modules and integrated hardware. The hardware module usually consists of cameras and lighting components of different types, which allow to adapt the system of acquisition of the images to the scenario of use.

The software module provides a set of tools that allows you to configure inspection tasks such as counting, measuring, comparing, reading codes and texts, among others. These tools can be combined and adjusted for different scenarios in product inspection.

Examples include checking the integrity of seals or the presence of contaminants in flasks in the packaging industry, assessing the homogeneity of surfaces in the detection of nicks and cracks in the wood industry, reading symbols, texts and markings in the printing industry, verification of markings on fabrics, among other cases.

Examples of commercial products found on the market are AutoVISION® (Microscan, 2014) and NI Vision Builder® (National Instruments, 2013). These products are marketed as complete solutions, comprised of both software and hardware components. These systems bring a software tool that provides a series of customizable inspection features. The set also features cameras with built-in lighting, high resolution, with autofocus and with the possibility of using triggers that allow synchronizing the acquisition with external sensors. In addition, a set of illumination components with different formats and models is provided to adapt the acquisition of images in the most diverse applications.

Figure 1 and Figure 2 shows examples of functionalities available in these tools, when applied in checking the quality of marking samples. In the inspection example, the tools are based on the ISO IEC 15415 standard, which determines some quality characteristics of 2D type marking, more specifically the Data Matrix. The software performs an analysis comparing the characteristics read in the current marking with the references of the standard.

The advantage of this type of tools is being ease of use, which does not require in-depth knowledge of image processing techniques and computer vision. Most features can be used with little or no parameter setting. The tools are very flexible and can be configured to inspect the characteristics of different types of products. As disadvantages, they are proprietary technologies and have relatively high cost. It is also observed that the compatibility of the software is usually restricted to the manufacturer's own hardware modules.

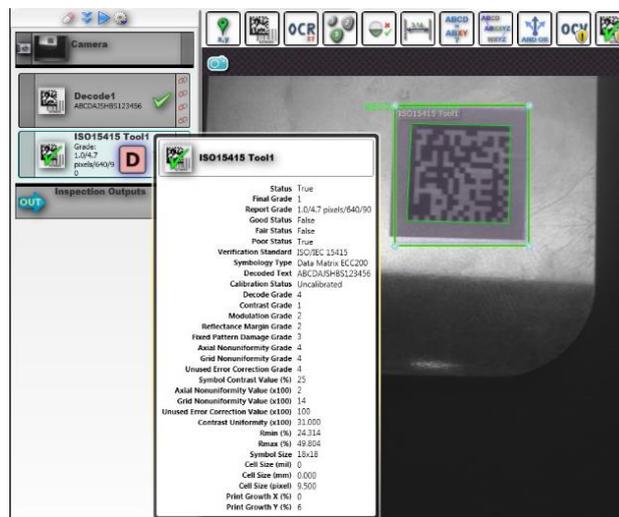


Figure 1. AUTOVISION® System Screen



Figure 2. NI Vision Builder® System Screen

To help in the creation of customized solutions for inspection or reading of codes by computer vision, there are free tools and libraries for image processing that facilitate the development work. For example, OpenCv (Bradski and Kaheler, 2008) is a software library compatible with different programming languages that provides a series of structures and functions of image processing, computer vision and artificial intelligence. This library has been widely used in academic or even commercial environments in the most varied subjects involving images, such as robotics, diagnostic imaging, human-computer interface, interpretation of satellite images, among others. Despite the advantage of already having a series of techniques implemented, their use still requires in-depth knowledge of them and of computer programming so that they can be combined in order that the expected results are achieved.

3. OVERVIEW OF A COMPUTER VISION SYSTEM

An automated inspection system can take on different configurations, depending on the application for which it is developed. However, a much-used configuration consists of an acquisition system and a processing system. Figure 3 shows a simplified illustration of a marking inspection system for the canning industry. In this configuration, an image is captured by the acquisition system. This image is transmitted to the processing system, where a computer, running a specifically developed software, analyzes the images to extract important data (Gonzalez and Woods, 2001). After processing, the system sends the information to the user by the human machine interface. In terms of software, among the main stages of the system's processing flow we have:

1) **Acquisition and Pre-processing:** This step consists in acquiring the images of the product to be inspected. Additionally, in this step, preprocessing of the images obtained may be necessary to improve the quality of the acquired image and, in this way, make it more suitable for subsequent processing. Among the processes commonly used in this stage can be cited the highlighting and restoration filters and color conversion.

2) **Segmentation / Detection:** It is at this stage that the regions of the images corresponding to defects, interest components or artifacts of the inspected object should be identified, isolated and localized. For this, both spatial and frequency domain techniques are used, mainly based on the variation of intensity or color observed in the images.

3) **Description:** In the description step, each identified object or artifact is described and transformed in a way that is most convenient for interpretation. Very employed descriptions are the area, position and shape (outline) of the object.

4) **Interpretation:** In this step, the information obtained from the previous steps is used to generate information of the highest level. Based on the contour describing an artifact located in the processed image, for example, one can estimate the type or presence of defects by making use of a pattern recognizer. From this step, inspection statistics are recorded, or the signals are sent to actuators if the inspection is being performed online.

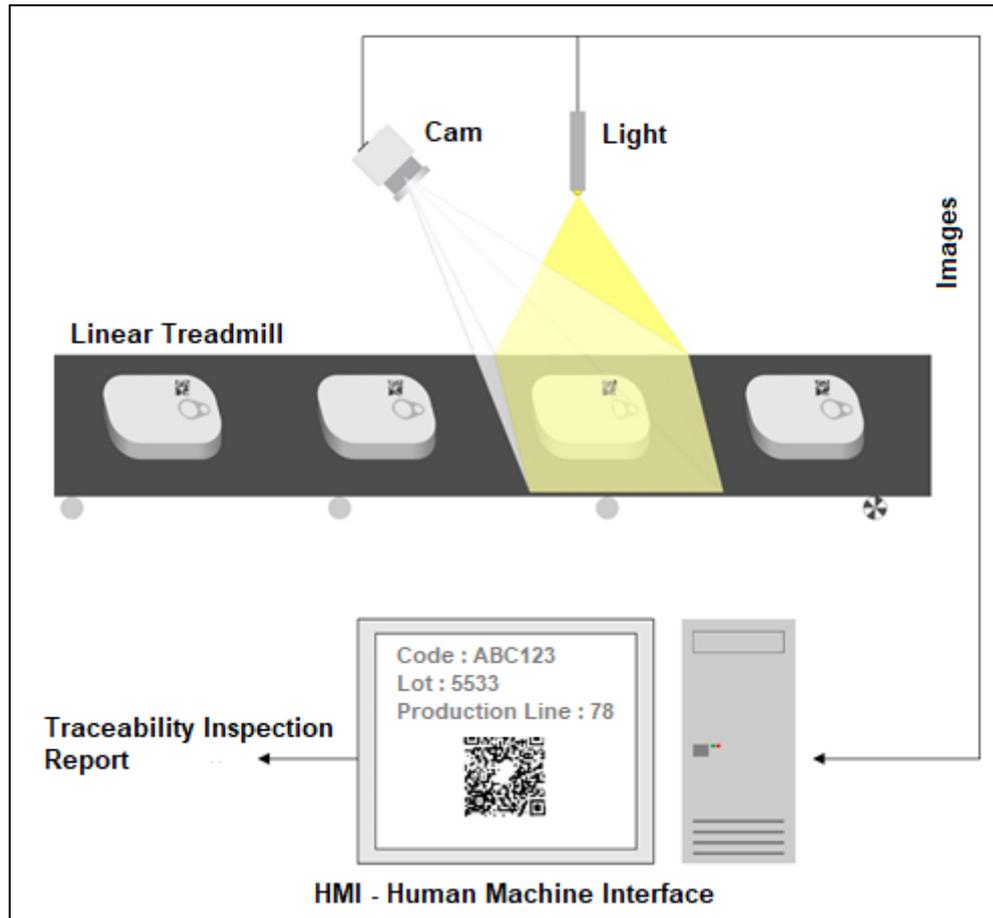


Figure 3. Example of simplified vision inspection/marking line

The presence of functionalities that implement processing techniques for each of these steps is essential to make possible to carry out the inspection or measurement, regardless of the usage scenario.

4. DESCRIPTION OF THE DEVELOPED TOOL

The main motivation for the development of the described tool is to provide an open source tool to extract quality characteristics of marking samples. This data will serve to guide the combination and configuration of parameters in the LASER recording process, so that the best compromise between quality and speed of marking can be obtained.

In addition to the combination of techniques suitable for detecting the set of defects or characteristics of interest in the inspected products, the configuration and use of the system represents an important aspect in the creation of the proposed solution. Since an important feature of the solution is the ability to quickly check the quality of markings, the definition of the processing flow must be easily configurable. Observing this, a linear flow approach was employed since the requirements were well defined.

It is also important to use open technology, with lower cost, with operational characteristics suitable for controlling small series (portability, flexibility, low configuration time, etc.). It is desirable that such a system be designed and constructed flexibly so that it can be adapted to different types of serial processes. In addition, the system must have an open hardware and software configuration for integration with other automated manufacturing systems.

Based on the presented scenario, the development of the first version of the system described in this work was guided by the following main functional requirements (Pressman, 2005):

- The system must perform the extraction of mark quality descriptors based on contrast.
- The system must allow the acquisition of images by both acquisition devices and image files.

In addition, the following non-functional requirements were selected:

- The system must be implemented using low cost components.
- The system must be implemented using open source technologies.

- The system should be easy to use.

To meet the described requirements, techniques were selected for each of the steps in a computer vision system, as described in Section 3. In Figure 4, the existing process flow in the proposed method is presented in a simplified way.

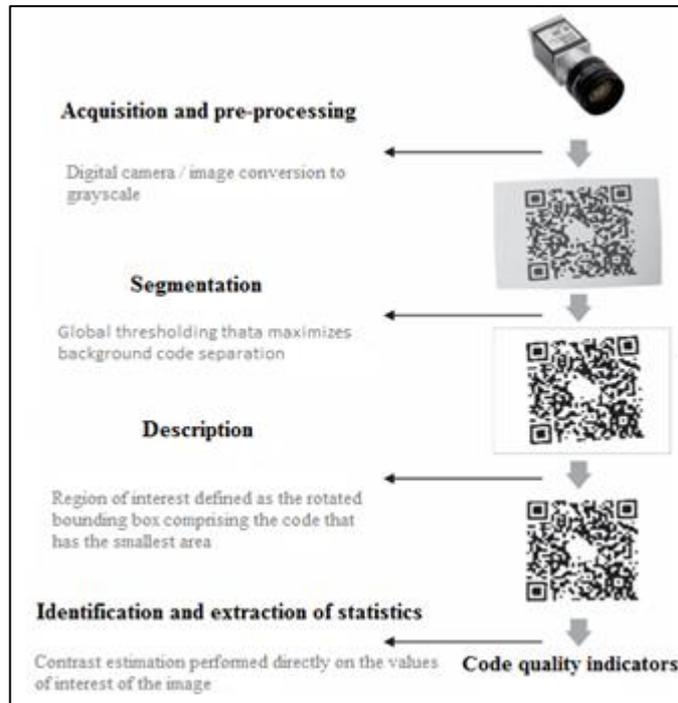


Figure 4. Simplified flow of the proposed method

In the acquisition stage, a digital camera is used, which captures an image of the part containing the code to be evaluated. As pre-processing the image conversion to grayscale is performed.

In the segmentation stage the global thresholding technique is used to separate the pixels corresponding to the code of the pixels corresponding to the background. Figure 5 shows the histogram that describes the frequency of intensity values for the pixels composing an image of a recording on a metal part. It is possible to observe the existence of two peaks that represent the intensities around the mean of the background phase value and the mean of the marking phase value.

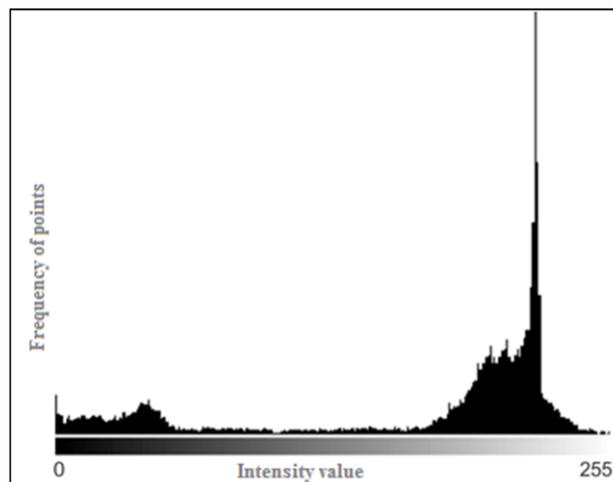


Figure 5. Histogram of intensities

In this way, a threshold intensity value can be conveniently selected which separates the phases. The binarized image $g(x, y)$ resulting from the segmentation of the original image $f(x, y)$ for a given threshold value T is given by:

$$g(x, y) = \begin{cases} 1 & \text{se } f(x, y) \geq T \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

The binarized image obtained in the segmentation step is used as the mask that separates the boundaries between the marking and the background. From this mask, the description of the code present in the image is performed by locating the region of interest of the image that contains the markup. This region is obtained by calculating the rotated bounding box of smaller area containing the whole code in the image. This description is convenient because it will eliminate 2D geometric transformations of translation and rotation resulting from the positioning of the part containing the code in the field of view of the camera.

Finally, the identification and extraction of code quality statistics are obtained by calculating the contrast value described by Equations 1, performed directly on the points that make up the marking region in the image.

Based on the described processing flow, a system was implemented that meets all functional and non-functional requirements listed in this section. To do this, the C++ programming language, the OpenCv Image Processing library and the Visual Studio development environment were used.

5. EXPERIMENTAL RESULTS

To validate the use of the system developed in the extraction of quality parameters of 2D codes (DataMatrix), tests were created to qualify these markings. By way of comparison, for these same tests inspection projects were created using the AutoVISION® and NI Vision Builder® commercial systems described in Section 2. The tests were performed using stainless steel samples marked by LASER, as shown in Figure 6.

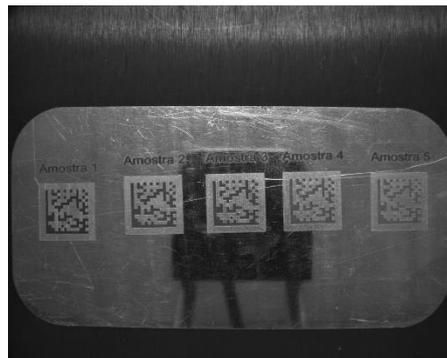


Figure 6. Marking Sample

Figure 7 shows the apparatus used for the acquisitions, both with the developed system (a) and with the commercial systems (b).



a) Developed System

b) Commercial System

Figure 7. developed system (a) and commercial system (b)

In the developed system, the quality analyzes of the markings were performed from a linear flow of acquisition, segmentation, description and identification and extraction as explained in section 4. Figure 8 shows the screen of this system during the inspection of a marking sample , where it is possible to check the contrast value.



Figure 8. System screen developed

In the AutoVISION® system, the tests were done with MicroScan's own tools for Data Matrix verification. Figure 9 shows the AutoVISION® system screen during the inspection of a marked sample, where the processing and results of the commercial tool can be verified.

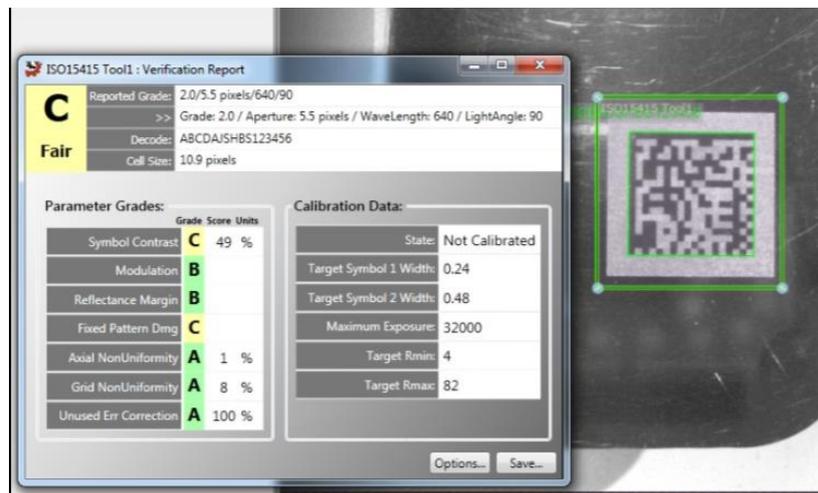


Figure 9. AutoVISION® System Screen

In the NI Vision Builder® system, the tests were done with National Instruments own tools for DataMatrix verification. Figure 10 shows the NI Vision Builder® system screen during the inspection of a marked sample, where the processing and results of the commercial tool can be verified.



Figure 10. NI Vision Builder® System Screen

For the qualification of the samples, 5 tests were performed with different samples, marked in a 20 watts LASER marking system, as in the marked sample shown in Figure 5. Each image was inspected in the AutoVISION® and NI Vision Builder® commercial systems in addition to the developed system, which should locate the image on the workbench. After locating the marking, the system should check the contrast values qualitatively. The results obtained by the three systems are shown in Table 1.

Table 1. Contrast values from inspection marked samples.

Samples	AutoVISION®	NI Vision Builder®	Developed System
Sample 1	30%	27%	28%
Sample 2	32%	28%	29%
Sample 3	36%	32%	33%
Sample 4	29%	26%	26%
Sample 5	24%	22%	24%

As can be observed all systems presented approximate results. However, the values of contrast varied within a range of $\pm 5\%$. This variation can be seen in the graph of Figure 11. Where results are shown for the AutoVISION® system in red, NI Vision Builder® in blue and the system developed in green.

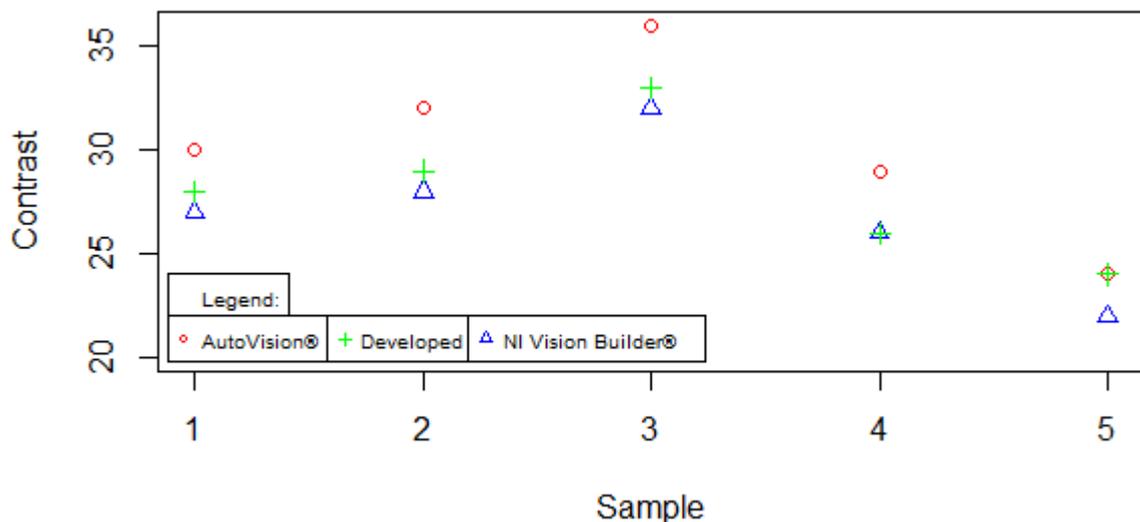


Figure 11. Comparison Graph

On the other hand, the detection or location of the marking region in the image was successfully performed by the developed system. It is also noted that the developed system could qualitatively analyze characteristics such as contrast, the most important indicator, to evaluate the characteristics of the markings, according to ISO IEC 15415.

6. CONCLUSIONS

In the present work the development of a system for inspection of 2D type marking (Data Matrix) based on computer vision is presented. The tool was developed with the aim of contributing to the dissemination and adoption of image-based inspection technology.

The use of a linear image processing stream contributed to the requirements of adaptability and ease of use being achieved. As can be seen in the tests performed with the tool, the system can be easily used.

The results obtained in the tests performed were similar to those obtained by a commercial system. In this way, the feasibility of the development of solutions of more low cost for inspection of products in this case marking 2D, using computational vision and processing of images is proved.

Future developments include the provision of more image processing operations, integration with communication protocols used on the factory floor and improvement of the parameter configuration, and automation of the definition of the same, when possible. In turn, the documentation and official distribution version will be prepared to make the tool available in the form of free software.

7. ACKNOWLEDGEMENTS

We thank our colleagues from CSI-IFSC (Intelligent Control and Supervision Laboratory), who provided insight and expertise that greatly assisted the research.

We thank Welle Laser company for assistance with using your Laser equipment, and for comments that greatly improved the research.

We would also like to show our gratitude to the LMP-LASER-UFSC (Laboratory of Precision Mechanics) for sharing their knowledge in LASER.

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9. RESPONSIBILITY NOTICE

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