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IMPLEMENTING A DATA MANAGEMENT STRUCTURE TO A COMPUTER ASSISTED RESTORATION PLATFORM

Adrian Septimiu[1] MOLDOVAN, Dan SAVASTRU[2], Nicolae PUŞCAŞ[3]

Lucrarea prezinta modul in care pot fi gestionate si utilizate datele de observatie obtinute cu ajutorul unui echipament complex destinat lucrarilor de restaurare a obiectelor de arta, pentru a creste eficienta operarii acestuia. Sunt identificate aspectele functionale perfectibile, se descriu solutiile avute in vedere si se propune o varianta de implementare fezabila. Studiul de caz se refera la un echipament construit in jurul unui microscop cu laser folosit la curatarea obiectelor de mici dimensiuni sau care necesita o curatare de precizie ridicata. Sunt analizate solutii hardware si software menite sa creasca randamentul activitatii de restaurare prin asistarea computerizata a echipamentului.

The paper presents how the observational data obtained from a complex equipment for the restoration of art objects can be managed and used to increase its operating efficiency. Functional aspects that are subject of improvements are identified, envisaged solutions are considered and feasible options are proposed to be implemented. The case study refers to a complex equipment built around a laser microscope that is used to clean objects of small dimensions or which are requiring high precision cleaning. Hardware and software solutions are proposed to increase the restoration work efficiency by a computerized assistance of the equipment .

Key words: restoration, laser cleaning, microscope, computer assisted, autofocusing

1. Introduction

Restorers' interest for conservation and restoration techniques using laser radiation is becoming more and more manifest in many areas of restoration, such as numismatics, graphics, miniatures, painting on paper, canvas and wood, mural painting restoration and others. Improved results in restoration can be achieved with a computer interfaced equipment which permanently assists the restorer.

The paper presents a case study of using observation data provided by an equipment containing a laser microscope to improve that equipment's efficiency and to modify its functional characteristics and capabilities such as to improve its performances. There are exemplified some functional aspects that could be subjects of future improvements. Also, there are considered some solutions to

[1] National Institute of Research and Development for Optoelectronics, e-mail: adrian.moldovan@inoe.ro
[2] PhD National Institute of Research and Development for Optoelectronics
[3] Prof., Physics Department, University POLITEHNICA of Bucharest, Romania

coordinate the computerized equipment by monitoring the main parameters that can be sources of errors, using repeatable and accurate operating procedures which will shorten the working time and will increase the cleaning efficiency and accuracy.

As a result, there are proposed practical options that lead to an improved equipment for restoration of art works, allowing the restorer to have an easier and error-free work operating a system that prevents accidental or inappropriate triggering of the laser pulse.

The improved system should actively assist the restorer by few safety related actions as autofocusing and autochecking of the alignment, and digital imaging, creating optimal work conditions for the operator.

In this way, the final decision, the intervention itself, is up to restorer, which has the ability to decide when, where and if is applying the cleaning laser pulse. This is a decisional act based on restorer's training and experience, including a personal component, too. These elements give the restorer's ability to consciously manage the whole activity, and this is an aspect it can not be attributed yet to a system based solely on a computerized system that automatically applies some algorithms.

Constructive solutions proposed to improve the laser microscope for cleaning of art objects are distinguished by the great versatility and ergonomics. The proposed system is suitable for precision and finesse cleaning operations in vertical (large paintings) and horizontal (documents, textiles, etc.) planes and three-dimensional objects.

Computer assisted laser cleaning gives the advantage of ensuring an optimal working environment in which the operator is relieved of technical issues related to the act of restoration itself.

The main objectives taken into consideration are:

- permanent computer assistance in checking the alignment between the laser spot and the targeting spot;
- computer assistance in bringing the targeting spot in the focal plane of the system and in generating a validation signal to continue the operating process. Alternatively, it is proposed to automatically bring the working area in the focal plane and its keeping in that plane, depending on local surface profile;
- permanent checking and storing of digital imaging frames to describe the subject before and after each pulse-interventions;
- capturing and storing of digital images;
- investigation of the object with a multispectral camera and a pyrometer camera, in order to acquire relevant information regarding the multilayer structure of the surface and to examine its response to heat stress to which it is subjected by the laser radiation.

To achieve these objectives are necessary intelligent peripheral devices as two or three axis automatic positioning devices, optoelectronic measurement of position and motion, drives with digital control, image capturing devices and software procedures for the acquisition of signals and image analysis.

The presented system is an important equipment of the ART4ART Mobile Laboratory, omnipresent on site to all longer applications[1]. The importance of control and self-control in restoration activity is also revealed by the quality of analitical investigations' results that are strongly related by laboratory environment or by the on-site experimental conditions [2,5]. Also several categories of interventions, like laser cleaning or enzime cleaning [3] require a particular attention that has to be assured for the objects based on organic materials, which are susceptible to accelerated ageing, too. Also, as a non-contact photonic technique, the laser cleaning regards important aspects from the point of view of fungal contamination control. [4]

2. Description of the analyzed equipment

To develop the data management structure we considered the original laser cleaning equipment which is equipped with targeting reticulation systems consisting of two side-oriented laser pointers at 46 ° from the optical axis of the microscope. These two pointers form a system which helps both framing the target area (framed by symmetry) and the correct image focusing (bringing the object's surface in the focal plane of the microscope objective).

Simplified diagram of this equipment is shown in Fig. 1. To simplify the drawing, only one side of the targeting pointers was draw at the upper part of the objective. As an alternative way of targeting is proposed a second system, consisting of a laser diode pointer whose beam is corrected with a cylindrical lens system. Its beam is inserted in the optical field of the microscope and is focused through the lens at the same point of the working surface with the cleaning laser beam.

The targeting system with two side pointers determines the relative position of the working surface from the focal plane of the microscope objective, as can be seen in Figure 2. The two pointers produce two pairs of side rhombs. The two pairs are displaced from each other if the object-plane is outside the focal plane (Figure 2).

The two sides pointers are located outside the microscope body, increasing its size and decreasing the shock immunity of the equipment which may cause misalignments of pointers and bad targeting or focusing.

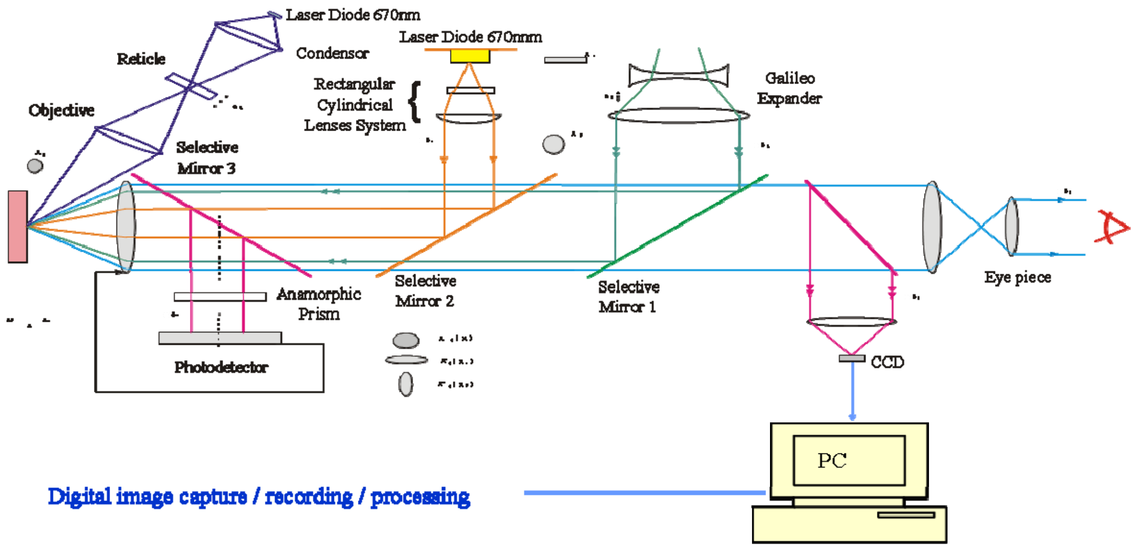

Fig. 1. The initial arrangement of the equipment

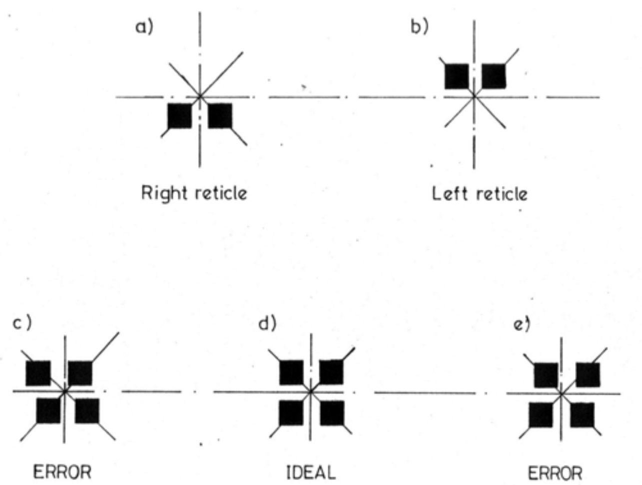

Fig. 2. The two pairs of targeting reticles and their relative position in three different situations: a) the image projected by the right pointer; b) the image projected by the left pointer; c) focusing in a closer plane then the focal plane; d) ideal focusing; e) focusing on a more distant plane than the focal plane.

From this point of view, we considered it is more practical to use the second version of the pointer, which uses the same optical field with the cleaning laser beam. This is presented in Fig. 1, where it shows how to use a 670nm laser diode to generate a targeting beam to be focused on the same plane and at the same coordinates with the laser beam. A quadrant photodetector is used to check the alignment of the targeting pointer with the laser beam. The error signal provided by the detector is applied to an optical correction system placed on the microscope objective.

We have adopted this method of checking the target point, but with some changes - we have considered that the targeting beam should be outside the visible region of the spectrum, to not bother the restorer's sight. The image of this spot affects the way colors are perceived, causing some confusion at the chromatic level. In addition, the correct observation of the cleaning effect produced by the laser pulse is disturbed. For this reason, it is proposed to replace this poiner with another pointer which produce a beam outside the visible region. In this way, the eye is not prevented from observing the details of the point where the sighting is made.

Since quadrant photodetectors are relatively expensive, we propose to use a different type of detector. This detector is an intelligent optical sensor used in the manufacture of optical mice. This type of sensor is very cheap and is produced in large quantities. Interfacing with this sensor is very simple and the information supplied by it can be easily processed using a small embedded system, with microcontroller, which can analyze this information. This embedded system can generate external correction commands.

Such a composed system (invisible pointer - inteligent detector - embedded system) can manage the resultant optical information and can provide further great benefits, such as intelligent control of the object-microscope distance to automatically obtain the correct distance at wich the object's image is focused, but also to obtain a digital image that doesn't present that disturbing red spot, superimposed on the object surface.

Changing of the object-microscope relative distance can be made through means of electromechanical devices with digital control. In this way we can obtain an automated system for finding the optimal focus position (AF) that can also control the displacement in a constant-distance plane, so that the surface scanning can be done remotely by teleoperation.

For stratigraphic monitoring of the surface layers of the investigated object is proposed to use a multispectral camera, while a pyrometer can be used to observe the thermal response of the treated surface. Information provided by these two cameras are stored together with probe images of the object before and after cleaning. These images has to be stored in a database that describes the process of cleaning and the effects recorded after treatment.

All imaging data are processed using a process computer that allows their storage and processing. It is also possible to generate a virtual image of the targeting spot, which is superimposed over the image of the treated surface.

Triggering pulses initiated by the restorer can now be filtered, so as to avoid launching a laser pulse if the image is unfocused or the targeting spot is not aligned with the laser spot. Watching the entire cleaning process on computer's monitor has the advantage of protecting the operator's sight from the backscattered laser radiation.

Equipment's computer also perform the function of a server, providing connectivity between a remote operator and the equipment located in the field. As a consequence of the proposed solutions, equipment functionality shows important improvements - the restorer can concentrate better on cleaning activity, as the proposed methods of checking the laser spot's position and autofocus relieve him of these tasks. This is an important aid in the restorer's work.

3. Results

The simplified scheme of the laser microscope, along with newly introduced peripherals that make up the proposed equipment is presented in Fig.3.

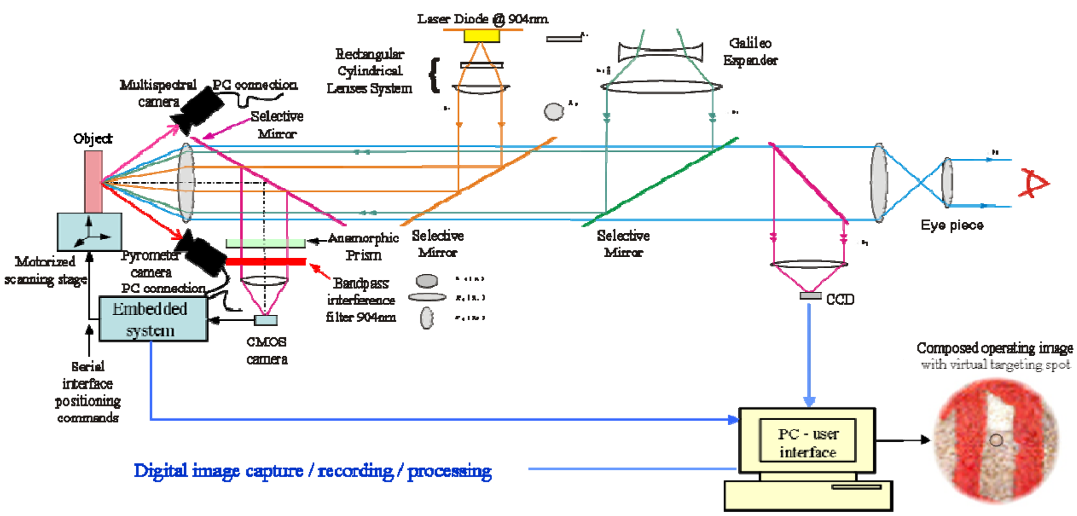

Fig. 3. Simplified diagram of the equipment

Imaging information obtained from this equipment are used to improve the efficiency of restoration activity and to avoid, as much as possible, operational errors due to the user. For this purpose, the equipment is improved by adding image acquisition devices and the necessary devices for moving the subject relative to the microscope's objective.

It is also described a logical diagram of operation designed to avoid situations in which the user could trigger a laser pulse on a non-targeted area or in conditions of a defocused image, producing damages on the surface to be restored.

In Fig. 4 is presented, in the form of a diagram, the logical sequence of operation.

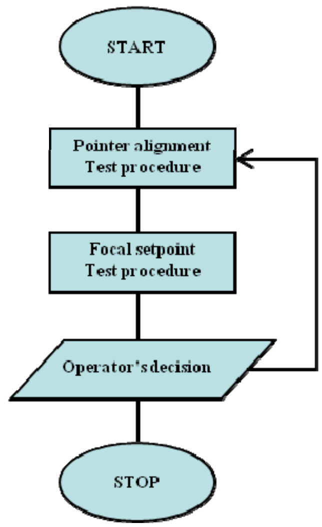

Fig. 4. Simplified logic diagram of the working procedure

To obtain an optimal coordination between the targeting spot and the incidence point of the cleaning laser beam with the object, a checking procedure of the pointer alignment with the laser beam is necessary.

The inspection of the laser pointer spot's position is to be performed with an optical sensor used for the construction of optical mice.

ADNS-3090 circuit, produced by Avago Technologies, is a specialized integrated circuit that includes a processor for digital signal processing (DSP) and a small CMOS camera of 900 pixels (an array of 30x30 pixels).

In an optical mouse, the DSP is used to perform image processing algorithms to measure the movement and to control the lighting of the surface whose image is acquired by the CMOS camera.

The proposed solution envisages the use of a small data processing unit built around a microcontroller and interfaced with the optical sensor via its serial interface. The information transfer is bidirectional, through the DSP's internal registers, using commands to write and read their values.

Information serially provided by the CMOS camera is presented as a string of bytes (900 bytes) transmitted by the DSP after it enters into the frame acquisition mode.

Each byte represents the 8 bits encoded information of light intensity received by each pixel, so that, for each pixel, we have 256 shades of gray. Geometrical dimensions of the 30x30 pixels array are approximately 1.5x1.5mm, which gives a good dimensional resolution, even for a 1:1 picture (about 50µm). Fig. 5 presents a sequence of images captured with such sensor while it is crossing over a black line. [6]

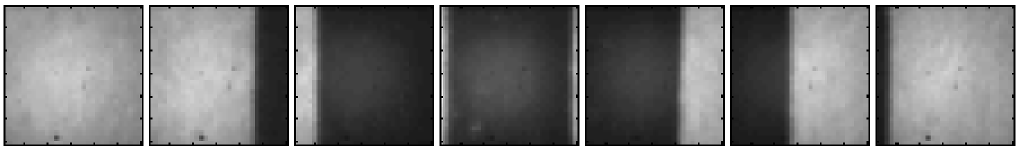

Fig. 5. Images captured with the sensor ADNS-3088 in the move over a 1.2mm thick black line.

3.1 Pointer alignment checking

To check the alignment of the pointer spot with the center of the image, corresponding with the position of the laser beam, a selective mirror that takes the pointer spot image is used.

The relative responsivity of the CMOS camera at the wavelength of the laser pointer (904nm) is only 0.3 of the value it has at 600-700nm, as can be seen in Fig. 6. However, the targeting spot's image may be obtained in good conditions.

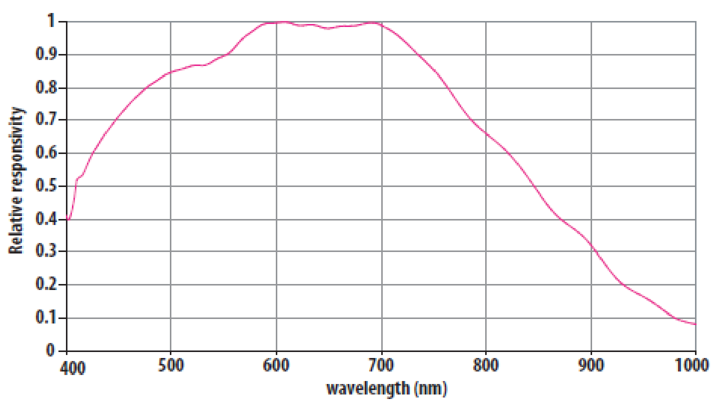

Fig. 6. CMOS camera relative responsivity versus the wavelength.

A 904nm filter is placed in front of the CMOS camera, so that the image obtained will describe the spot position within its field. This position is determined using the microcontroller attached to the sensor and compared to the center of the image field, this reference having the same object-coordinates as the laser spot has.

The alignment verification microsystem provides an output signal which confirms the position of the targeting spot in the center of the image. If it shows over limit deviations from the central position, then generates an optical warning signal, which consists of intermittent displaying of a virtual reticle which is superimposed on the operating control image diplayed on the monitor.

From the software point of view, this adjustment procedure is described in logic diagram called "*Pointer_alignment_test_procedure*".

Through this function, the microcontroller continuously check whether the image of the pointer's spot is at the center of the CMOS matrix. When the image is centered, a flag is set that validates the eventual triggering command issued by the user.

Fig. 7 shows the logical diagram of this procedure.

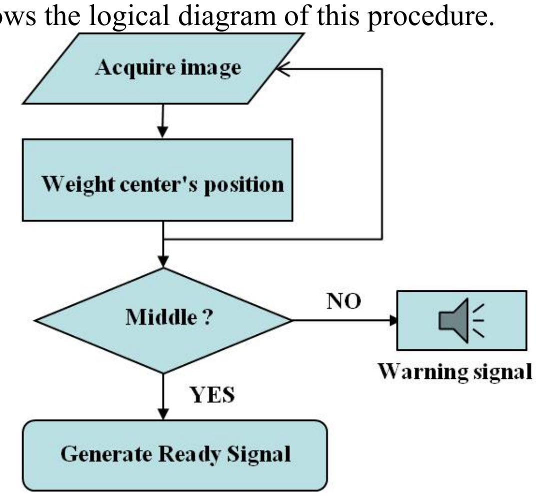

Fig. 7. Pointer_alignment_test_procedure

3.2 Maximum contrast focusing method

Two methods are proposed to check the focusing on the object surface. The first of these is using the image of the object before applying the filter at 904nm. The method envisaged is called "maximum contrast method" and according to it a defocused image always has a lower contrast between adjacent pixels than it should have in the condition of a correct focusing.

To be used, this method requires a second CMOS camera, which provides black and white 30x30 pixels images of the area centered on the focal point of the microscope's objective.

A passive process is used to check the focus, similar to the one used by digital cameras with auto focus function - the image acquired by the CMOS sensor is analyzed in different areas of the image field.

Maximum contrast method consists in finding the object position in which its image shows maximum contrast, as being the position of correct focusing. To measure the contrast, neighboring pixels brightness differences are analysed. Differences between intensities recorded by adjacent pixels are measured, in order to find their maximum. The area of analysis is chosen so that to include those adjacent pixels between which the differences of intensities are maximum. To do this, the entire image (30x30 pixels) is analysed and an appropriate area is chosen.

Searching for maximum contrast position (correct focus), consists of vertical displacement of the cross table and permanent measurements of image's contrast - if contrast decreases, then the moving direction is incorrect and should be reversed. If a mobile microscope is used to treat a fixed object, the correction signal is applied to the motorized positioning system of the microscope. Fig. 8 shows different frames in different focusing stages.

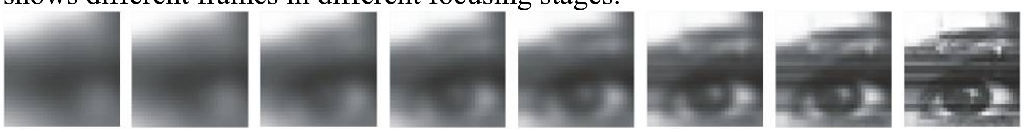

Fig. 8. 30x30 pixels frames. Left - defocused, right - focused.

3.3 Spot minimization focusing method

This method proposes to use the same image that is used to check alignment of the targeting spot. Its image has, according to a correct focusing, a known size.

Using the spot's image one can determine the relative position between the object and microscope which corresponds to the minimum illuminated surface, as the correct focus position. The decision to modify the relative position between object and the microscope, so that to bring the working surface in the focal plane, is based on this determination.

Also, the spot image, taken through the filter of 904nm, can be used to apply the maximum contrast method, described above. The advantage of this picture is that there is no need for the second CMOS camera.

Fig. 9 shows an example of a 30x30 pixels image, in which is visible only the targeting spot, in different poses, from unfocused to focused.

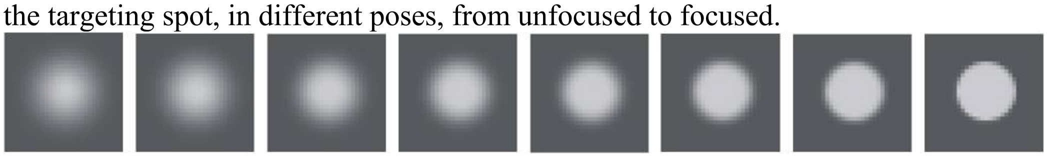

Fig. 9. Pointer spot, acquired on a matrix of 30x30 pixels. Left - defocused, right - focused

Fig. 10 shows the simplified logic diagram of the function that brings the investigated surface in the focal plane.

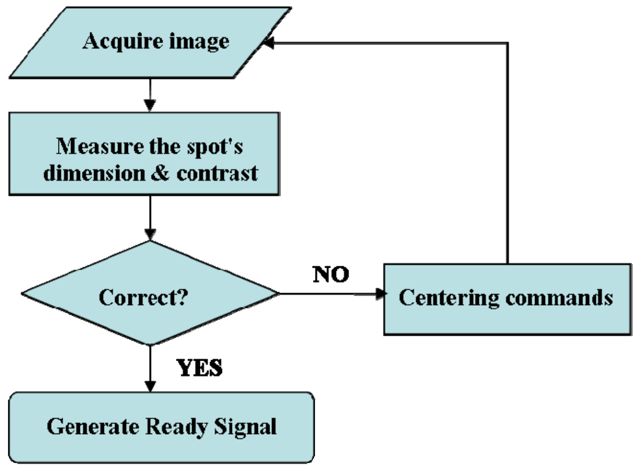

Fig. 10. Focal_setpoint_test_procedure.

Focal_setpoint_test_procedure is a software function that commands the changing of the relative position between the object and microscope by the means of a motorized, positioning stage. These displacement mechanisms can act either on the microscope table or on the object cross table. Using a three-axis positioning mechanism has the advantage that the entire process can be managed remotely by an operator qualified in restoration activities.

The function is permanently tracking the targeting spot's dimensions and the contrast of its image, commanding displacements of the cross table, in an arbitrary sense. If the contrast decreases and the spot size increases, it means that the movement is made in the wrong sense and should be reversed. If contrast increases, and the spot diameter decreases, the moving direction is correct.

To find the correct focusing position, this software function searches this position by carrying out a mapping of the measurements depending on the position of the cross table.

Accuracy checking is achieved by imposing an override, characterized by voluntarily overcoming of the correct position, for validating the solution found. If the differences in intensity passes through a maximum and then decrease, then the determined maximum value is correct, and the cross table should be brought into the position corresponding to that value.

As a calculation method, the behavior of the first derivative of the contrast signal and of the diameter of the targeting spot can be used. Optimal focus position is reached when the derivative is zeroed.

These mathematical algorithms have to be implemented in an autofocus application written for the microcontroller that manages that function. Movement commands for the cross table are generated also by this microcontroller, so that the final solution is compact and independent of other functions. The same solution can be applied when using an adjustable focus lens when the microscope is mobile and the object is fixed.

Displacement commands are applied to the cross table positioning devices, such as H101A, produced by Prior Scientific. Fig. 11 is presenting such a device.

Fig. 11. Motorized scanning stage, Model H101A - Priority Industries for automation microscopes.

These devices have a stroke of 114mmx75mm and positioning resolution is better than 1µm. They accept linear motion encoders and are controlled through a serial RS232 or USB interface. Positioning repeatability is better than ± 0.7µm.

The two adjustment functions, pointer alignment and autofocus on the object, runs continuously in the loop, so that users always have the equipment in standby status. In this situation, operator may practically trigger the laser at any time.

Images of the view field provided by CCD and CMOS cameras are stored prior and after the generating of the triggering pulse. These images are witness-images, and represent evidences of intervention, by saving frames of *pre* and *post* laser pulse.

3.4 CCD Camera

It is used for continuous visual inspection, but also as a source of imaging information which are the control samples (*pre* and *post* laser pulse). The computer display provides an image consisting of the working surface of the object image which is virtually superimposed with the laser spot box framing. Position and size of this spot are determined from image analysis provided by the CMOS camera.

Following the process after the CCD camera images has the advantage of protecting the user of the equipment from the backscattered laser radiation.

Use of an infrared diode laser spot has the advantage that it produces images invisible to the eye. It does not influence the perception that the restorer has on the image of the object under restoration. Instead of a red spot, which may prevent the observation of certain details of color, restorer only sees on the composite picture the virtual box of the targeting spot, presented in a fine circular reticle.

5. Conclusion

The paper followed the presentation of some improvements it may be done on a computer assisted equipment built around a laser microscope. This approach brings major advantages to laser cleaning methods applied in restoration and concentrating on the specific case of cleaning small objects or objects that show fine details. In these cases it is necessary to operate at a certain optical magnification to ensure thorough investigation and precision cleaning of the treated surface. This type of activity requires the use of laser microscopy. Have been proposed and discussed technical solutions that are designed to ease the restorer's mission by conducting a computer assisted process. Proposed solutions has the purpose to minimize the number of operational errors caused by improperly triggering of the laser while the image is not focused or the laser spot targets elsewhere then the position of the reticle is. In addition, by introducing a motorized scanning stage, which can change the object's position relative to the microscope, it creates the premises for building a teleoperated microcleaning system, which can be used remotely via the Internet.

Research of phenomena underlying the laser cleaning process aimed at eliminating any risk of damage to the substrate. Eliminating the danger of possible damage to the substrate requires a subtle understanding of the phenomena that occur at the cleaned object's surface and sometimes gives rise to subjective and dependent arguments and principles of working experience of the restorer. For this purpose, cleaning equipment has been improved with a multispectral camera and a pyrometer camera, which provides information on the multilayer structure and surface temperatures developed on the object, as methods to control and self-control the restoration activity.

This paper presents an innovative way to ensure the acomplishment of the increasingly stringent requirements from users - ergonomics, safety in operation, portability, protection of the studied object and the safety of the operator.

The proposed solutions for marking the incidence point and for providing the automated focus are also original.

Last but not least, the proposed construction systems keep the basic function of a measuring optical microscope, allowing the operator to do quantitative assessments in the observation field, which no other system ensures.

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