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3D laser cleaning as a novel approach to artworks conservation

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Abstract. Until recently, restoration cleaning has been carried out primarily manually. Manual laser cleaning is a time-consuming process that requires highly skilled restorers. The introduction of automation, which increases the quality and speed of laser cleaning, will significantly expand its application range and reduce the complexity of restoration work. In this article, we present the results of our experimental work on automated 3D laser cleaning. The proposed approach allows for precise cleaning of objects of complex geometric shape under the control of a CNC machine. To remove dirt from the surface of such objects, we have developed an original approach based on a combination of three-dimensional scanning of the object and obtaining a point cloud of the surface to be cleaned, creating a control program for surface cleaning on a CNC machine. The demonstration of the automated cleaning process took place on corroded steel samples of complex geometric shape. A fiber ytterbium pulsed laser with an average power of 100 W with a wavelength of 1.06 microns and a pulse duration of 100 ns was used for cleaning.

Keywords: laser cleaning, fiber nanosecond laser, conservation, artworks, CNC, 3D scanner

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Лазерная 3D-очистка как новый подход к сохранению произведений искусства

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Аннотация. Ручная лазерная очистка — трудоемкий процесс, требующий высокой квалификации реставраторов. Внедрение автоматизации, которая повышает качество и скорость лазерной очистки, значительно расширит область ее применения и снизит сложность реставрационных работ. В этой статье представлены результаты экспериментальной работы по автоматизированной 3D-лазерной очистке. Предлагаемый подход позволяет проводить точную очистку объектов сложной геометрической формы под управлением станка с ЧПУ. Демонстрация автоматизированного процесса очистки проводилась на образцах корродированной стали сложной геометрической формы. Для очистки использовался волоконный иттербиевый импульсный лазер со средней мощностью 100 Вт, длиной волны 1,06 мкм и длительностью импульса 100 нс.

Ключевые слова: лазерная очистка, волоконный наносекундный лазер, реставрация, произведения искусства, ЧПУ, 3D-сканер

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Introduction

The use of laser technologies in conservation of cultural heritage has been continuously evolving over 50 years. It was first proposed in 1972 by American physicist John Asmus for the removal of black crusts from the surface of stone artifacts [1]. The validation of advanced laser cleaning techniques has been extensive and found application in many parts of Europe, North America, and Australia, especially for stone and metal objects. Laser-based diagnostics have also specialized their tasks toward material analysis, defects detection and multidimensional documentation. The most notable of these uses of laser radiation are holography, holographic interferometry, laser-induced fluorescence, Raman spectroscopy, photoacoustic spectroscopy, optical coherence tomography, laser vibrometry, and 3D scanning profilometry. As a result, the value for laser techniques in art conservation has been recognized widely.

Today, lasers are considered an innovative tool in conservation, promising selective and delicate cleaning applications. Among the most promising tasks of laser cleaning is the removal of dirt and other contaminants from the surface of sculptures and other Cultural Heritage [2–5]. Although laser treatment is frequently used in artworks conservation there remains much open room for further research concerned with development of novel methodologies and new approaches.

Until recently, restoration cleaning was carried out manually. Manual laser cleaning is a time-consuming process that requires a highly qualified restorer, which limits its wide practical use.

In this article, we present the results of experimental work on automated 3D laser cleaning. The proposed approach allows for precise cleaning of objects of complex geometric shape under the control of a CNC machine.

To remove dirt from the surface of such objects, we have developed an original approach. This approach consists in creating a three-dimensional model of an object using 3D scanning and creating a CNC controller program based on this model for cleaning the surfaces of an object on a CNC machine. The controller program scans the surface of the object along the trajectory in the form of a snake, precisely maintaining the working distance between the surface relief and the laser head. The laser head forms a laser sweep strip on the surface of the object. The surfaces of the object are scanned with a laser beam until the required degree of purification is achieved.

Materials and Methods

Optical/laser scanner Shining 3D EinScan HX was used to scan the surface of the object being cleaned and create a cloud of surface points. This scanner provides fast 3D scanning by combining LED light and laser scanning mode. Next, controller program in G-code for CNC was created using the CAM system. Cleaning was carried out by an automated laser cleaning machine ALONP-100IM (manufactured by NPP VOLO Ltd., Russia, St. Petersburg), including laser fiber module (wavelength 1.06 microns, pulse duration 100 ns, maximum average power 100 Watts). The laser head forms a laser sweep strip on the surface of the object in the form of a line, the length of which can vary from 10 to 50 mm.

Results and Discussion

The experiments were carried out on steel samples that had undergone years of atmospheric corrosion, and there were also layers of old paint and bitumen on their surfaces. Figure 1, *a* shows a fragment of the preparation of the CNC controller program. The trajectory of the laser head movement precisely corresponds to the profile of the treated surface. After preparing the controller program, the sample was positioned on the machine table and the cleaning program was started (Fig. 1, *b*).

a) *b*)

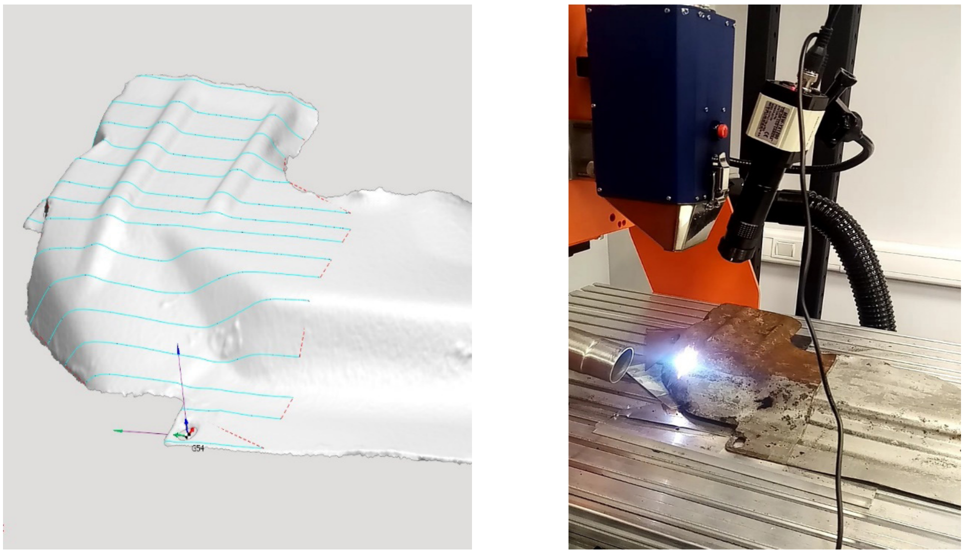

Fig. 1. Laser cleaning process. Preparation of CNC controller program (*a*), restoration object is positioned on machine table, cleaning program is started (*b*)

Optimal laser operation parameters for removing loose rust and paint are: spot diameter of focused laser beam is 100 microns, pulse repetition rate is of 100 kHz, pulse energy is of 1 mJ. The laser cleaning device uses a galvanoscanner to create a sweep strip. The machine moves the laser cleaning device perpendicular to the sweep strip, thus creating a cleaned rectangular area. Fig. 2 schematically shows the formation of the laser processing area. To obtain a uniform effect over the entire cleaning area, the next pass is carried out with an offset of half the length of the sweep.

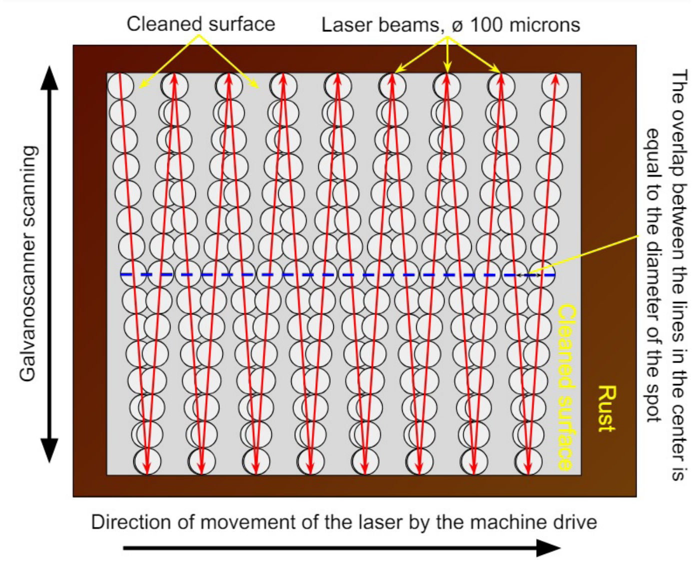

Fig. 2. Scheme of forming a processing strip with a single pass of laser cleaning

Cleaning is carried out in evaporative mode. The power density in the laser spot is sufficient to vaporize the contamination in a layer several microns thick in one pulse. An additional contribution to the cleaning process is made by the shock wave from the resulting plasma and thermal stresses associated with rapid heating and cooling of the treatment area [6–7].

The processing quality was monitored visually during the laser treatment process controlled by program operation (Fig. 3). The number of repetitions of the program and the laser operation parameters were adjusted to obtain the required cleaning quality.

Fig. 3. Visual control of degree of laser cleaning

Conclusion

The results of our experiments showed that automated laser cleaning has several advantages over manual laser cleaning. First, the cleaning performance of the automated system is 1.5–2 times higher than that of the manual system, as the optimal scanning trajectory is chosen and the working distance between the laser and the surface to be cleaned is accurately maintained. This results in a higher quality of cleaning and a better surface appearance. Second, since laser cleaning can be done 24/7 without interruption, it is easier for the restorer to work. They only need to monitor the quality of the process and ensure there are no errors. Third, automated laser cleaning is perfect for large-scale objects as well as objects that are similar or identical objects.

At the same time, it should be noted that the proposed approach can be recommended mainly for cleaning garden and park sculptures, as well as Contemporary Art objects.

In the future, it is important for us to pay attention to automating the process of controlling the degree of purification and adjusting the controller program during cleaning. This will allow us to further increase productivity and the quality of processing process.

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