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A Robotic Method of Laser Cleaning of Antique Materials

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Abstract. The presented article deals with issues related to laser cleaning of materials, especially the surface of historic elements. Typical types of dirt occurring on the surfaces of historic elements are characterized. A theoretical basis for the interaction of a laser beam on the surface of elements is presented. The proposed method of robotic laser cleaning eliminates the disadvantages of the manual process.

Introduction

Defects associated with external surface contamination are usually a result of the settling of volatile dusts of various origins and the formation of oxides. Surface contamination may also be a result of chemical reactions on the surface of a detail caused by external factors such as acid rainfall. Dirt may also be a result of an act of vandalism consisting in the application of various types of paint. The presence of plant-based soils, such as mosses and lichens, is also a particular type of a defect. It is also quite common for salts and hydrated minerals to penetrate the surface of stone or ceramic elements, which results in the appearance of stains and efflorescence. Often, mineral materials are not homogeneous and consist of many different compounds. Some compounds have a tendency to leak to the surface after hydration. Selected examples of contamination of historical details are shown in Figure 1.

Fig. 1. Examples of defects of architectural details (volatile dusts, limestone blooms, soils of biological origin)

Materials found in the constructions of historical elements require appropriate and delicate renovation treatments. In special cases, such treatments may involve cleaning the surface of a detail or removing top coats to apply new ones [1, 2]. Among the available and currently used methods, many are invasive and may cause too much interference in the structure of a detail. At the moment, scanning a detail with a laser beam is one of the youngest cleaning technologies under development [3, 4]. Through the use of a coherent, high energy coherent beam of a specific wavelength, such a solution guarantees obtaining results unattainable by using other, previously used cleaning technologies.

Laser cleaning process

Laser surface cleaning is a process in which a laser beam with energy capable of removing impurities from it is used [5, 6]. In this process, pulse lasers with a wavelength of 1064 nm and pulsed operation are most commonly used. Typically, pulse times of the order of 10 ns and energy at the level of hundreds of mJ are used, which corresponds to the power in the pulse of about several dozen of MW [7].

A laser beam with a power density of the order of 10^6 W/mm^2 interacting on the contaminated surfaces can affect them in two ways, depending on the thickness and nature of this layer. In the case of a thin layer, the impulse causes its almost immediate evaporation and transition into a plasma state manifested by a strong emission of optical radiation [8, 9]. This mechanism usually occurs on metal surfaces covered with a thin layer of oxides, patina or a thin layer of paint. In turn, thick layers of impurities under the influence of optical radiation pulse undergo very rapid heating, resulting in the phenomenon of thermal expansion, strong shear stress at the boundary layer of contaminants - the substrate that causes detachment from the substrate and falling off in the form of larger fragments [10]. This phenomenon is particularly intense when it comes to brittle and porous coatings such as rust, thick paint coatings or mineral particles glued to the surface, for example fragments of plastering mortar or putty. In both mechanisms, the best results, i.e. the removal of impurities, are obtained with high reflexivity of the substrate, protecting it from damage and low reflexivity of the impurities covering it, which thanks to the high absorption of radiation ensures fast progress of the cleaning process. Selected examples of laser cleaning effects are shown in Figure 2.

Fig. 2. The effects of using the laser cleaning method

Like any technology, also the laser cleaning method requires the fulfillment of specific parameters. Among other things, it is necessary to specify the necessity to meet the perpendicularity of the laser beam to the surface to be machined and to keep a specified distance of the scanning head from the surface of a workpiece. Parameters such as radiation power or pulse frequency are selected depending on the type of dirt of the material being cleaned. In the case of manual manipulation of the scanning head, when cleaning details with complex geometry, it is difficult to meet the two key previously mentioned requirements. Inappropriate beam routing can have far-reaching negative effects, which should be kept in mind when cleaning valuable or unique details. The laser cleaning process also has an adverse effect on personnel operating laser devices.

Developed method of robotic laser cleaning

One of the ways to eliminate disadvantages of the classic, manual laser cleaning process is its partial or full automation or robotization, by placing the scanning head on the device performing the

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sequence of working movements in the automatic cycle [11]. Among the known solutions, six-axis industrial robots with the RRR configuration provide the greatest manipulation possibilities [12, 13].

The presented method of robotic laser cleaning involves the use of an industrial robot to guide the scanning head of the laser device. Despite numerous benefits, the use of an industrial robot for the laser cleaning process has also some problems. The most important of these is the need to reprogram the robot each time for machining various details that have a different spatial geometry. For industrial robots, a number of standard trajectory planning methods are envisaged, but none of them is beneficial for robotic laser cleaning.

In the presented method, planning the manipulator trajectory is directly based on the knowledge of the geometry of the workpiece. Such a method guarantees each time correct parameters of processing of the cleaned part. It is an offline programming method in which a generation of paths for the robot is done automatically by specialized CAM systems with implemented postprocessors for the robot class.

In order to accomplish this task, it is necessary to pre-acquire the geometry of the workpiece using spatial scanning methods. Laser optical scanners are used for this purpose. These devices operate on the principle of triangulation, generating a cloud of node points of the scanned part. The next stage is solid modeling in order to fill any possible deficiencies in the model that could have arisen in the scanning process. In this stage, the cloud of points is usually transformed into spatial geometry with the possibility of being exported to typical 3D data exchange files via software usually provided by the scanner manufacturer.

The next stage involves automatic generation of paths for the robot manipulating the laser cleaning head. Based on the geometry of the scanned detail, the CAM software prepares the path of the scanning head, while optimizing the sequence of motion of the robot's drives. The final effect of this stage is to generate a program code appropriate for a given robot. A full simulation and visualization of the robot's work movements is also carried out. The sequence of stages of the presented solution is illustrated in Figure 3.

Fig. 3. Stages of the developed technology

The last stage of the presented solution is to implement the created code in the robot control system. After determining the correct speed of movement for the effector, the actual cleaning process of the part under consideration begins. It is very important that the cleaned part is oriented in space according to the orientation adopted during the trajectory planning step. Depending on the thickness of the contamination layer, the process can be carried out repeatedly. If the material contamination is uneven, the operator can remotely control the switching of the laser beam.

Summary

The project concept of a robotic laser cleaning station presented in the article is a result of joint work undertaken with an industrial partner. Based on the experience of manual handling of the cleaning head, the process can be unambiguously characterized as tiring and tedious. Constant exposition of operating personnel to the effects of dangerous laser radiation is also important. Following the example of other well-known solutions, the concept of position automation was developed. However, the method of planning the trajectory for the robot turned out to be a critical problem. It was proposed to use the method of trajectory planning based on the knowledge of the geometry of the cleaned part. The presented laser cleaning process in a robotic manner has also many advantages. The most important ones include improving the quality of the cleaned surface, speeding up the process and eliminating the risk to the operating staff.

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