Scientific Visualization, 2022, volume 14, number 5, pages 108 - 118, DOI: 10.26583/sv.14.5.08

About Development and Application of a Software Platform for Machine Vision for Various Laser Technologies

A.A. Molotkov[1,A,B], O.N. Tretiyakova[2,A,B], D. N. Tuzhilin[3,B]

[A] Moscow aviation Institute (National research University) MAI, Moscow, Russia
[B] Industrial Research LaboratoryLLC, SPC "Lasers and equipment TM" LLC, Moscow, Russia

[1] ORCID: 0000-0002-9335-5219, karacerr@gmail.com
[2] ORCID: 0000-0003-0256-4558, tretiyakova_olga@mail.ru
[3] ORCID: 0000-0002-8570-1732

Abstract

This paper is devoted to solving problems of machine vision and scientific visualization in a field of industrial implementation of new laser technologies, in particular, the technology of selective laser melting. The result of the development of a specialized machine vision software platform is demonstrated, which makes it possible to simplify the solution of a wide range of machine vision and scientific visualization tasks. The presented work also considers a number of particular issues of video recording of processes in isolated environments, determining the boundaries of objects in an image, analyzing and processing video data, forming and presenting a pattern of heat distribution in a three-dimensional object, based on data obtained as a result of a numerical experiment in accordance with the mathematical model of the process under study implemented by us. The article also demonstrates the results of combining calculated data on the geometry of the product, data obtained by analyzing video data from visual observation tools, with thermal distribution data. This approach makes it easier for technologists to analyze the production process, identify critical areas such as overheating and non-melting zones, and select technological parameters for the selective laser melting process. The results of using the created software platform in various production technologies are demonstrated.

Keywords: SLM, software platform, machine vision, optoelectronic devices.

1. Introduction

Selective laser melting (SLM) technology is a layer-by-layer additive manufacturing technology using a laser (heating a fine metal powder with various types of laser radiation intensity distributions and consolidation). Today, the SLM method is the most rapidly developing and widely studied [1-4] additive manufacturing technology. During the industrial implementation of this technology, we faced the problem of visual control, analysis and data visualization. A large number of scientific works are devoted to various aspects of the development of technological solutions using methods and algorithms of machine vision (Computer Vision), for example, [5-14]. Moreover, problems are often considered, the solution of which allows the use of explicit linear algorithms. Examples of such problems are: finding barcode or QR code, determining the position of the product, adjusting the processing path, analyzing the number and quality of holes in the perforation of the material, determining the geometry of the working sheet, quality control of the weld, determining the geometry of flat products or products made by selective laser melting SLM.

2. Architecture of the proposed software solution

Mentioned tasks are solved in a built software environment with an emphasis on accessibility and ease of use. The user can collect data from various image sources, define a processing sequence using various image processing filters (Fig. 1), and perform analysis using prepared software tools. For this purpose, the LAMachineVision software platform was made (Fig. 1).

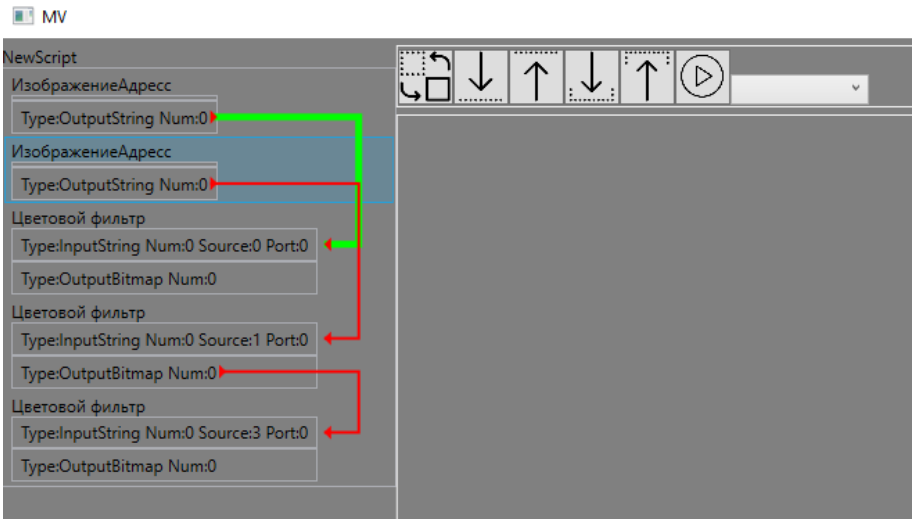

Fig. 1. Sequence of image processing.

The software platform uses a visual programming approach that has proven itself by providing a wide range of users with the ability to solve machine vision problems. The same principle applies to such development environments and platforms as LabVIEW [11] and Cognex VisionPro. LAMachineVision is written in the C# language of the .NET Framework version 4.7.2. WPF is used to create the main user interface, using DirectX graphics technology and using the declarative XAML language. The user interfaces of the tools used (various filters and processors) are implemented using WPF and Windows Forms tools using the GDI/GDI+ graphics technology. Due to the use of the C# language, the main operating system for the LAMachineVision platform is Windows version 7 and higher. The main part of the platform is written according to the Model-View-ViewModel (MVVM) pattern.

Using the link establishment function, a connected directed graph is formed, along which the system will subsequently transfer data from sources to filters and further along the route specified by the user. The only condition for this construction is the work with absence of cycles in the solution graph.

The use of a high level of abstraction allows us to exclude a wide range of restrictions for developers, allowing to implement own filters and processors and simply embed them into the platform using the API, allowing third-party users, including technologists and researchers who do not have programming skills, to solve a wide range of machine vision tasks. API (Application Programming Interface) - an application programming interface, a description of the ways (a set of classes, procedures, functions, structures or constants) in which one software can interact with another software. In order for a new filter to be embedded in a decision tree, it is enough that its outer software shell implements a simple IProcessing interface with a small number of supported properties and methods:

- string Name { get; set; }
- int Num { get; set; }
- ObservableCollection<IInputStep> InputSteps { get; set; }
- ObservableCollection<IOutputStep> OutputSteps { get; set; }
- ObservableCollection<Info> InfoInputSteps { get; set; }
- ObservableCollection<Info> InfoOutputSteps { get; set; }

- void DoProcess();
- void UpdateInfo();
- Page UiPage { get; set; }

The transfer of information is carried out using I / O "ports", also with a high level of abstraction, there are no additional requirements for both the user interface and the specific implementation. Thus, each filter and processor is an object that implements the IProcessing interface, receives data for its work from input ports, performs some action and passes the result of its work further along the decision graph through the output port.

This approach allows both using your own implementations of machine vision algorithms and using third-party libraries and frameworks, in particular, AForge.NET and OpenCV solutions were used. To connect various data sources, interaction with Basler machine vision cameras using the Pylon SDK packages, with Hikvision cameras using the Hikvision SDK packages, and IP cameras using the DirectShow framework is implemented.

3. Practical applications

One of the possibilities implemented by the platform is the interaction with various camera models. In particular, the use of Basler matrix cameras (Fig. 2) was tested, which are mainly used in factory automation, traffic monitoring, retail, as well as medicine and life sciences.

Fig. 2. Matrix camera.

Further, the data from the camera are used for subsequent analysis or video recording (Fig. 3) of the processes under study. The use of machine vision cameras allows you to monitor processes in environments inaccessible to the observer. In particular, in DMD technology (direct metal deposition, technology for manufacturing metal parts by direct metal deposition).

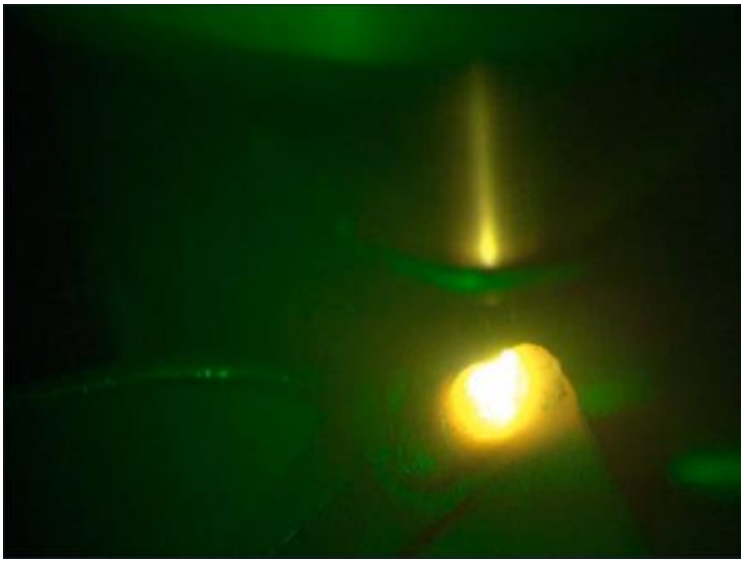

Fig. 3. Video recording of the DMD process of welding a turbine blade.

One of the most common machine vision tasks is object recognition. One of the special cases of such a task in industry is finding a sheet in the working field of the machine. One of the options for solving a similar problem using the capabilities of the platform under consideration has been implemented. A Basler matrix camera is used as the data source. Sheets can be located in different parts of the working field, have different shapes and consist of different materials, so it is supposed to formulate the task as a search for abstract objects in the image. For this, various image comparison filters are used. The idea of the approach is simple: get an image of an empty workspace, then get a new image of the space with the sheet already in place and recognise its location by comparing it with the original image. In addition, the implemented algorithm for correcting radial distortion caused by the use of wide view lenses is demonstrated (Fig. 4).

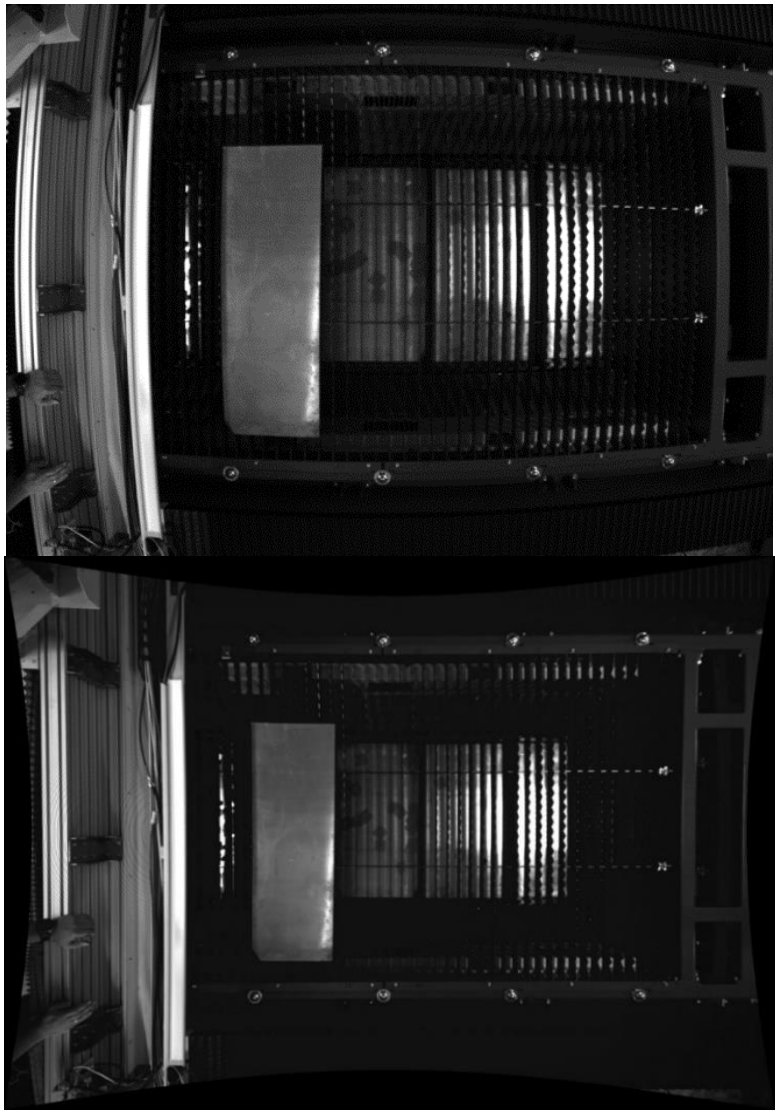

Fig. 4. Correction of distortion.

Several filter options have been implemented that determine the difference between two images, allowing you to compare a field with a sheet and a field without a sheet and find the desired object in the image. For color images, there are several similar processors, which are based on different metrics for calculating the color distance between pixels, and several methods for finding corners in an image using different implementations of corner detection algorithms.

An algorithm for determining the contours of an object from previously found angles has been developed and implemented (Fig. 5, 6).

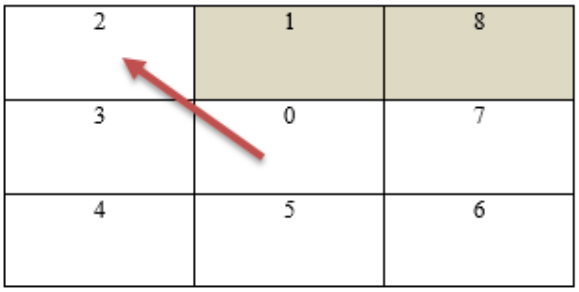

Fig. 5. Searching for boundaries algorithm (inner boundary).

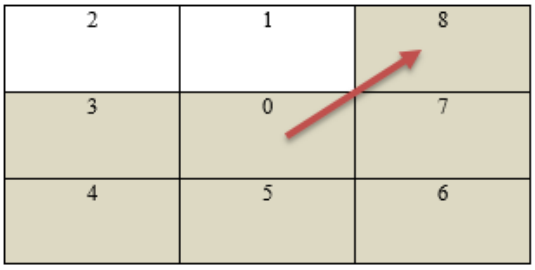

Fig. 6. Searching for boundaries algorithm (outer boundary).

The idea of the algorithm is simple: based on the filters mentioned earlier, the image is binarized (most often based on comparison with the background image) and the set of corners is determined, the upper left unused corner is taken from the set of defined ones. If the top pixel is black, then the bypass is counterclockwise; if it is white, then the bypass is clockwise. Thus, we divide the contours into outer and inner.

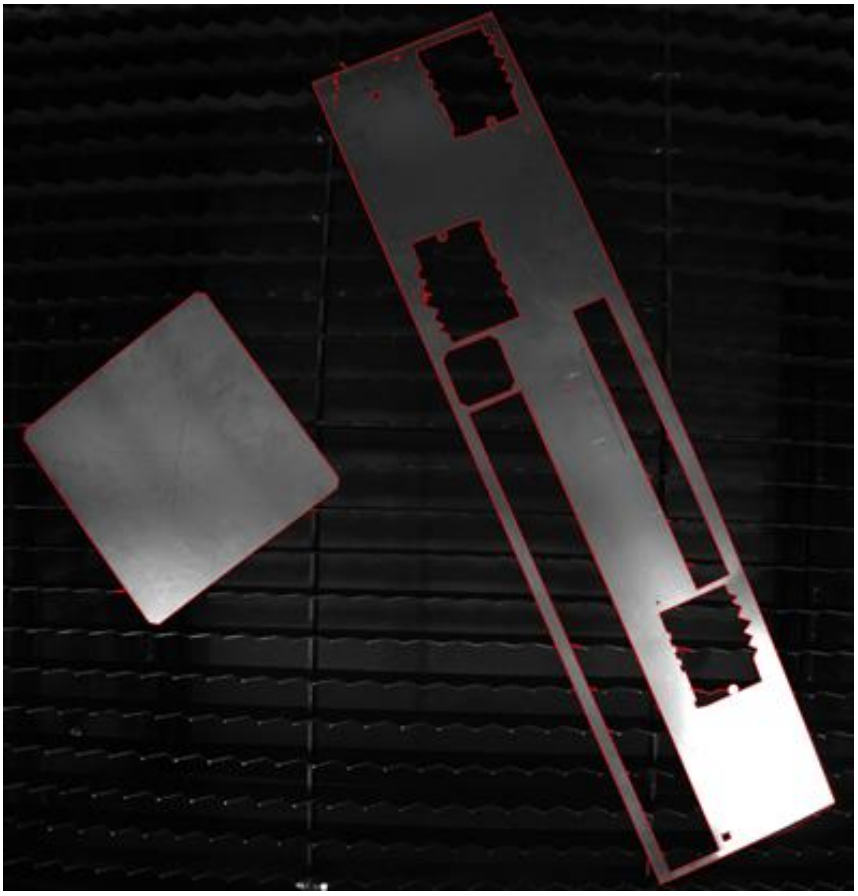
Fig. 7. Found sheets.

The quality of the result obtained depends on the quality of the image, lighting and the accuracy of the selection of processing parameters. The same approach is applied to find the geometry of the fused layer in the SLM process. The preview image is a photo of the previous layer. The new image is a photo of the next fused layer. The problem of finding and analyzing the quality of holes during perforation is solved in a similar way.

Data on the fused layer of powder material are processed in a similar way in the manufacture of products by the method of selective laser melting. After determining the geometry of each layer, it is compared with the pre-calculated one and the so-called “layer map” is formed (Fig. 8), on which the data of the temperature model are subsequently superimposed.

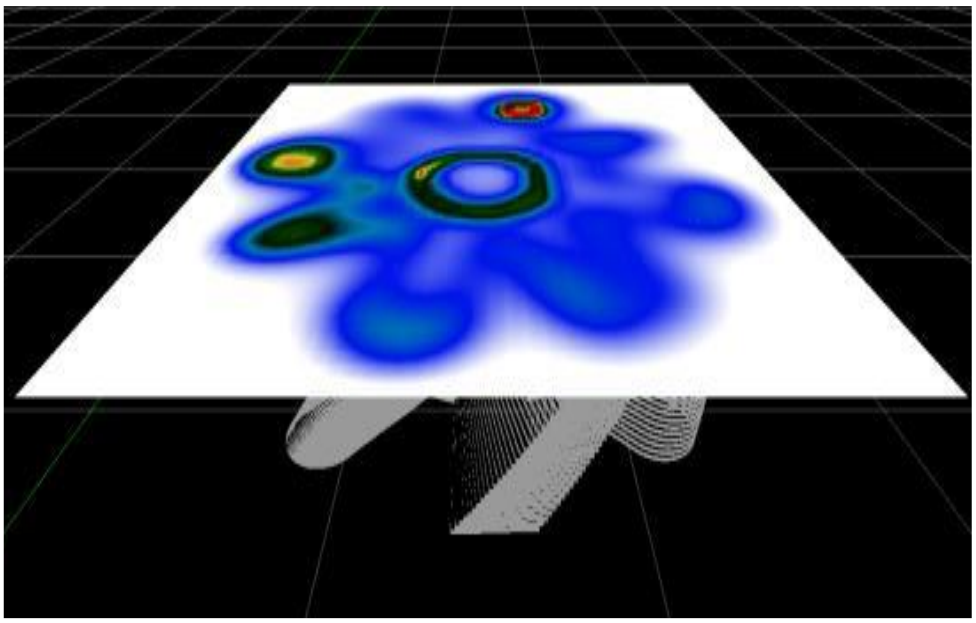

Fig. 8. Composition of temperature data on the product layer
(one of the representation models).

4. Software complex as part of the tracking system

Tracking systems are widely used in laser technology for processing products from various materials. When using pulsed laser radiation of the picosecond and femtosecond range in the process of micromachining, there is often an increased sensitivity of the parameters of the technological process of processing to the deviation of the focal length of the laser-optical system from the surface of the product.

In laser micromachining processes, micron deviations are critical, therefore, accurate and fast methods of compensating for the error in real-time movement of the product surface relative to the optical system during processing are required. The algorithms and methods of machine vision included in the developed software automation platform make it possible to provide the required parameters of the micromachining process.

For the processing of dielectrics and metals, a system for automatically controlling the position of the laser beam focus (Fig. 9) is proposed, using the idea of a laser optical rangefinder (triangulator), which has the following advantages:

1. non-contact measurement, which is safe for the workpiece,
2. the ability to work with dielectrics,
3. no mechanical moving joints,
4. the possibility of using the system in especially clean rooms,
5. high performance, i.e. high measurement and processing speed, and high accuracy,
6. the possibility to obtain a wide range of characteristics by changing the source, detector and geometry.

In general terms, the automatic control system for the position of the focus of the laser beam of special technological equipment using a laser optical rangefinder can be classified: 1.

According to the basic characteristics. 2. According to the location of the laser rangefinder relative to the optical system of the working laser. 3. If possible, synchronous operation of measurement systems, calculation of the automatic control system for the position of the laser beam focus and the control system for the kinematic systems of the machine tool with numerical control. 4. According to the design of the rangefinder. 5. According to the type of adjustment on the Z axis. 6. According to the capabilities of the built-in analysis of the measured data. A number of devices have the ability to pre-filter data, ensuring the stability and repeatability of the results.

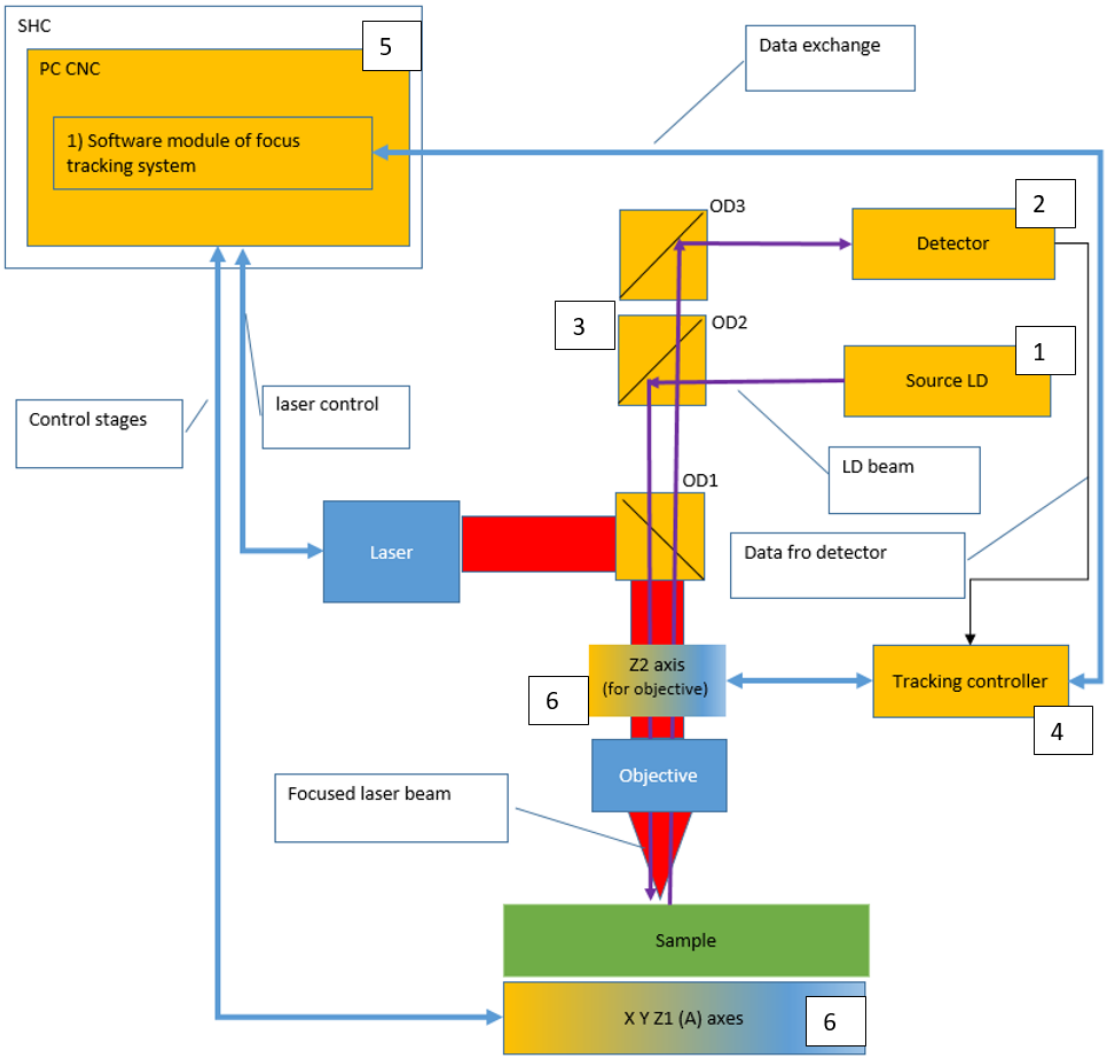

Fig. 9. Common block scheme of the automatic control system for the position of the laser beam focus.

According to the location of the laser rangefinder relatively to the optical system of the working laser, the system of automatic control of the position of the laser beam focus (Fig. 9) proposed is coaxial, which ensures the operability of the tracking system for any laser processing trajectories in the XY plane. According to the type of adjustment along the Z axis, two possible versions are possible - with the movement of the sample itself (Z1), and in the version with the movement of the objective (Z2). Focus adjustment by moving the lens is recommended because the lens is lighter than a product with a holding and alignment tools. This allows for more dynamic focus adjustment. The system is synchronous, i.e. focus adjustment is performed during laser processing. By type of execution, the system is distributed, i.e. it's ready for integration into an opto-mechanical laser processing system.

The automatic control system for the position of the laser beam focus includes:

1. "Source (LD)" - a laser diode (Laser diode LD), the source of laser radiation of the tracking system. The LD emission wavelength for most dielectrics is in the range of 650~900nm. This makes it possible to use optical coatings of optical components between the first and second harmonics of the operating range of laser radiation, as well as the possibility of integrating a coaxial video system with illumination. There is a possibility of amplitude modulation of radiation by external control.

2. "Detector" - a matrix or line camera with a digital interface.

3. "OD1", "OD2", "OD3" - optical dividers, optical elements, the dielectric coatings of which are selected depending on the radiation wavelength of the "Source (LD)" and the working laser for micromachining "Laser". The presence of "OD3" is due to the possibility of using a coaxial video channel for automation and application of machine vision algorithms.

4. "Tracking controller" - the main controller of the automatic focus position control system, which reads and processes data from the detector in real time, mathematical processing of the received data and calculation of the focus position, control of the Z coordinate, by sending commands to the CNC system of the laser machine. This controller works autonomously, a communication line of this controller with the CNC system is also provided for transferring parameters and monitoring states. The controller of the automatic focus position control system is implemented on the basis of a field-programmable gate array FPGA.

5. "SHC" - a software and hardware complex of a laser system, including a software module for automatic tracking of the sample profile in the CNC system of the laser installation, as well as a user interface for controlling, configuring and testing the automatic focus position control system. The software and hardware complex can work autonomously without the participation of the CNC.

6. Z axis (Z1/Z2) - can be implemented on any type of drive that provides the required accuracy and dynamics: linear drives, piezo actuator, etc. The Z axis is controlled by the interaction of the controller with the appropriate driver.

The collimated laser beam of the automatic focus position control system from the LD source passes through the power lens to the surface of the product, part of this radiation is reflected from the surface, passes back through the power lens, and the reflected beam is recorded on a linear detector. The position of the peak on the linear sensor of the detector corresponds to the current distance between the lens and the surface of the workpiece. One of the peak positions is stored in the tracking controller as the focus position. While tracking the sample surface, the tracking controller moves the lens in such a direction that the position of the current peak tends to the position of the stored focus. The variable length of the return pass to the camera ensures the adjustment of the scale of the automatic focus position control system, namely the accuracy and measurement range at a fixed camera size. Setting the source beam collimation allows you to adjust the size of the laser spot on the surface of the product.

Thus, the possible types of configurations of surface tracking systems are analyzed, the configuration is selected, its composition, structure and principle of operation are described.

5. Conclusion

Because of the work carried out, it became possible to:

1. Solve a number of tasks of machine vision and scientific visualization in the framework of the industrial implementation of new laser technologies, in particular, the technology of selective laser melting.

2. Create a specialized machine vision software platform that makes it possible to simplify the solution of a wide range of machine vision and scientific visualization tasks.

3. Provide the possibility of video recording of processes in isolated environments, determination of the boundaries of objects in the image, analysis and processing of visual data, formation and presentation of a picture of heat distribution in a three-dimensional object, we

implemented process based on the data obtained as a result of a numerical experiment in accordance with the mathematical model of the object.

4. Realize the combination of calculated data on the geometry of the product, data obtained by analyzing video data from visual observation tools, with data on the thermal distribution of the parameters of the selective laser melting process.

5. Create a system for automatic control of the position of the laser beam focus, designed to be built into laser micromachining systems and laser systems for additive technologies and which can significantly improve the quality, repeatability and productivity of laser micromachining processes using pulsed laser radiation of picosecond and femtosecond range.

The created machine vision software platform has been tested and implemented in software and technological solutions used in high-tech equipment.

6. Acknowledgments

The authors are grateful to the management of the group of companies "Lasers and Apparatus TM" for assistance in the material and technical support of experimental studies and modeling of the process under consideration.

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