HIGH-TECH MECHATRONICAL ADAPTABLE EQUIPMENT FOR INTEGRATED DIMENSIONAL CONTROL OF COMPONENTS FROM AUTOMOTIVE INDUSTRY

Adrian-Cătălin VOICU [1,2], Gheorghe I. GHEORGHE [1,2]

[1] National Institute of Research and Development in Mechatronics and Measurement Technique, 6-8 Pantelimon Road, 2nd district, Bucharest, Romania

[2] Doctoral School of Mechanical Engineering, Valahia University Targovişte, Str. Lt. Stancu Ion, no.35, Targovişte, Romania

E-mail: voicu_adrian_catalin@yahoo.com

Abstract. *The biggest problem of intelligent measurement and integrated control is the need to ensure the quality of the product and the manufacturing process, regardless of the field, or intelligent industrial processes. In the development of high-tech intelligent techniques and technologies, with increasing demands for quality have been designed and developed, different mechatronic systems for intelligent integrated dimensional control, nationally and internationally accepted. Thus, new techniques and technologies and new systems for dimensional control who integrating the new requirements of the developments, were realized and developed by specialized companies. The creactivity of human being and his correlation with the requirements of permanent increase of the living standard, constitutes the basis of developments in moderns society. In a perfect world or in an perfect integrant production environment, the tridimensional measurement systems, who provide the quality and the integrated control in the production line, would be able to measure all the necessary parameters in a single step, with no errors and to send the results to the manufacturing networks with computers, in useful formats for CNC equipments.*

Keywords: integrated control, 3D laser scanning, automotive industry, mechatronic systems, new technologies

1. INTRODUCTION

According to the latest statistical data published by the European Association of Motor Vehicle Manufacturers (ACEA), the annual turnover achieved by European companies from auto industry had elevated to over 843 billion in 2013, representing 6.6% of community gross domestic product (GDP) [11].

Quality of a product is all the appropriations that gives it its use value. This notion reflects the degree to which the product satisfies social needs, according to technical and economic parameters, aesthetics, the usefulness and economic efficiency in the exploitation and consumption.

The mechatronics metrology, whit all the theoretical and practical aspects of measurements, is used as a process for measuring and verifying the macro and micro geometry of the work piece surfaces and to assess the quality of the products together with the precision and accuracy.

The importance of new technologies for economic development is widely recognized, given the impact that technology can have on the success or failure of business survival of the companies, especially in an environment of intense competition and global.

With the increasing demands for quality, during the development of intelligent manufacturing techniques and technologies, have been designed and developed, different high-tech mechatronic systems for intelligent dimensional control that use some new techniques, accepted worldwide [1].

In this regard, new techniques, technologies and constructions on dimensional control systems integrating the new requirements of the development stage of society, were realized and developed by specialized companies.

The biggest problem of intelligent measurement and integrated control is the need to ensure the quality of the product and the manufacturing process, regardless of the field, or intelligent industrial processes [10].

With the new scientific discoveries, new high-tech mechatronic, adaptronic and ultra-precise systems for dimensional control whit new principles of operation have been designed, in integrated conception, with a wide application in integrated control processes [1].

The automobile industry is one of the most important industries in the world, where the manufacturing systems engineering, control methods and techniques, present a particular interest by the economic outcomes, especially whit the reduction of working time and production costs.

2. 3D DIMENSIONAL CONTROL TECHNOLOGIES IN AUTOMOTIVE INDUSTRY

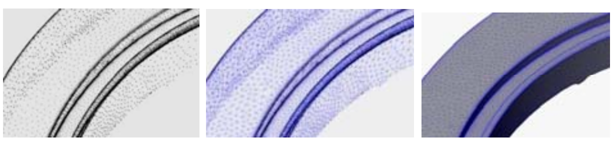
Normally, the products quality control is performed using manual methods and some various statistical sampling procedures, which are generally time consuming and raw materials. This also assumes the transfer of parts from the production place, with consequences over the manufacturing time or with jams, sometimes in the production process.

In the engineering industry the old technologists are large consumers of raw materials and energy and the results are few or weak. The biggest challenge for the Romanian automotive industry is the growth of high-tech products, results of intensive research with high added value.

The disadvantages of the classical control is the this is performed after the pieces have already been produced, and the number of scrap pieces cannot be longer influenced. To minimize this number of scraps are necessary additional costs and much more for the adjustment of recoverable scraps. In machines construction, and in others industrial fields, the quality control of products is organized under four forms: before processing, after processing (passive), during processing (active) or integrated. [3].

Modern technologies for dimensional inspection respond to a variety of typical measurement specifications in various industrial applications that require precision measurements need. Both measurement accuracy and ease of use of portable instruments measure imposed as a standard in the field of quality control in terms of dimensional metrology equipment type laser tracker articulated measuring arms.

3D scanning is the technique of digital information copying process of the geometry specifications of a physical solid object, so it is known as digitization. *"3D digitization"* is a process that uses a contact or non-contact digitizing probe that capture the form of the objects and recreate them in a virtual work space whit a very dense network of points (xyz), in the form of 3D models. Data are collected in the form of points and the resulting file is called " cloud points" (Fig. 1). "Points cloud" information type are typically a network of small polygons (simple mode), which are called 3D polygonal network or mesh. The overall accuracy of a 3D acquisition system depends above all on the precision sensor and device acquisition (acquisition with contact) or the structure of the acquisition (acquisition without contact). This accuracy can vary from micron to millimeter size and acquisition of a few points to several thousand points per second.



3D point cloud 3D mesh Resulting surface

Fig. 1. 3D digitization

The new methods of measurement, verification or 3D dimensional control can be: "with contact" (coordinates measuring machines (CMM), and "contactless" or non-contact, divided into two categories: optical and non-optical.

Reliability, accuracy, ease of integration and low cost are important factors that require improvement and "software" support more and more intelligent allowing the automation of calculation and expression results in immediate terms used (point clouds, polygonal surfaces reconstruction, direct export CFAC tools or machines for prototyping) [7].

Laser and video-laser sensors used in the integrated control technologies have been developed as alternative to replace the sensors (probes) with contact, where the physical contact is not possible. They are generally used in the case of fine or finished surfaces, super-finished or with sharp edges.

The 3D scanning technology on which the optical laser process includes the following steps:

- The projection of laser beam onto the object;
- The reflection of the laser beam from the object which is collected by digital sensors;
- The calculation of the 3D spatial coordinates (X, Y, Z) of the point using algebraic equations;
- Storing of the location of the coordinate point in the system as part of a point cloud, resulting in millions of points;
- The creation of 3D digital mesh from the points, using techniques for digitalization, which are used to create the 3D models;

Digital data are used for rapid engineering, rapid prototyping or inspection of the product [2].

3. INTELLIGENT MECHATRONIC SYSTEM WITH LASER FOR MEASUREMENT AND 3D INTEGRATED CONTROL

The classical mechatronic systems for integrated dimensional control achieved their goal on short term, but in the long-term we need new investments in other types of high-tech mechatronic systems to verify parts with a greater diversity. So, is necessary to create some high-tech mechatronic systems for integrated dimensional control with new features:

- Modularity - easy adaptation to new types of pieces and family of parts;

- Adaptability – to the new range of parts through the modules designed for their verifications;

- Intelligent automation – the ability to signal process and decide different situations and to report the dimensional evolution of the piece.

Because the new adaptable intelligent *mechatronic* system with laser for 3D integrated control from this project is used in the production halls or in metrology laboratory in the auto industry environment, the following hardware and software structure of the high precision adaptive laser scanning system is proposed (Figure 2) mainly because the parts can have different shapes and complex surfaces.

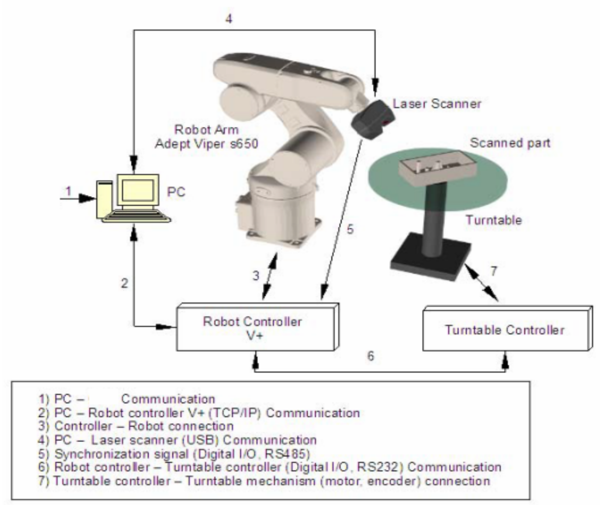


Fig 2. Hardware and software structure of the laser scanning system and 3D processing of objects

The proposed system for 3D scanning, acquisition, alignment and inspection of data is composed from the following basic elements (Figure 3):

Fig. 3. 3D Laser Scanner

Fig. 4. Articulated robotic arm with 6 degrees of freedom

- 3D laser scanner : whit acquisition system, hardware and software library (image improvement, alignment, eliminating points in excess, color combination).
- Anthropomorphic vertical robot arm articulated, with 6 degrees of freedom (e.g. Mitsubishi RV-2SD/SQ) – mechanical system, assisted by a multitasking controller whit 80 programs, guided by the visual feedback from the control room (GVR), learning module and control software for robot motion (Fig.4).
- Rotary table (optional) with precise positioning in the control loop of the movement and of the rotation speed (Fig.5).

Fig. 5. Rotary table

The rotary table is controlled as external movement axis by the controller of the anthropomorphic robot arm, and the motion of the table is synchronized with the movement of the robot, in other words, the robot has added a supplementary degree of freedom (the 7^{th}). The necessity of the rotary table is mainly because the robot arm cannot reach behind the object without causing a collision or without changing the position of the object that it is measuring [4]. The scanning device have a Class II laser type of short distance, with triangulation, having two or three CMOS acquisition sensors (high definition cameras) [6]. The optimum scanning distances are between 51 mm and 251 mm, the width of the scanning line can vary between 30 and 100 mm. The average measurement accuracy at point level are around 10 μm. The acquisition ratio of system is between 50 and 500 frames per second depending on the resolution, and the number of points on a scanning line is equal to 500. This laser acquisition system interfaces with the PC using a PCI Express standard port and has a RS485 digital signal, which can be used for synchronization with the robot controller.

The mechatronic adaptable system used for sweeping the laser beam is a vertical anthropomorphic articulated robot with 6 degrees of freedom. The repeatability of the system movement it is 0.01 mm. The displacement domains (6 axes, 6 pivots) of the robot system are: axis (joint) 1: ± 170° axis (joint) 2: -170°, +45° axis (joint 3): -29°, 256°, axis (joint) 4: ± 190°, axis (joint) 5: ± 120°, axis (joint) 6: ± 360°. Composed maximum speed at the top is 8000 mm/s.

The software that are used, allow the permanent knowing of scanner position, the creation of scan pathways and graphical interface whit the PC. Because we want to realize an accurately device that can read at every 1 millisecond the position of the robot system, the acquisition rate of the device will be that of the scanning device [4]. Measurement accuracy is of the order of microns, whereas both the scanning device and the articulated arm will be high precision devices. Inspection of simple parts is i realized by the 2D artificial sight system (optical camera) that can provide a measurement accuracy of up to 0.007 mm. If the quality requirements a high precision or a complex measurements, the proposed solution will used the 3D scanning system consisting of the robot arm articulated, the scanning device and the rotary table. This solution offers the flexibility and adaptability of the quality control system and a precision of the microns [5].

The scanning device being mounted on the robot arm in the gripper place, it is considered that the scanned object can be bounded by a vertical cylinder [9], having the diameter and the maximum height specified as follows:

- above complete scan, maximum height 500 mm and maximum diameter 750 mm;
- lateral scan, maximum height 700 mm and maximum diameter 400 mm;
- combined lateral and above scanning, maximum height is 500 mm and maximum diameter 500 mm.

The scanning time estimated for a simple surface will vary depending on the chosen devices.

Scan time estimated for a simple surface will vary depending on the selected devices:
a) Quick Scan with 1mm resolution:
• 2500 mm2 / s, with a forward speed of 50mm / s and an acquisition rate of 50 frames / second;
• an area of 50 x 50 mm2 will be scanned 1-5 seconds.
b) Scan accurate, with a resolution of 50 µm:
• 375 mm2 / s, with a forward speed of 7.5 mm / s and an acquisition rate of 150 frames / second;
• an area of 50 x 50 mm2 will be scanned in 10-20 seconds.
c) Scan Ultra-Sharp, with a resolution of 10 micrometers:
• 175 mm2 / s, with a forward speed of 2.5 mm / s and an acquisition rate of 350 frames / second;
• an area of 50 x 50 mm2 will be scanned in 1-5 min.
The scan times were calculated under the conditions that the average width of the scan line is 50 mm and depends on the complexity of the surface.

The realization of integrated dimensional control is a complex process, and in order to obtain maximum efficiency it is necessary the use the best program of measuring that realizes the best connection and communication between the user, the measuring device and the measuring devices [8].

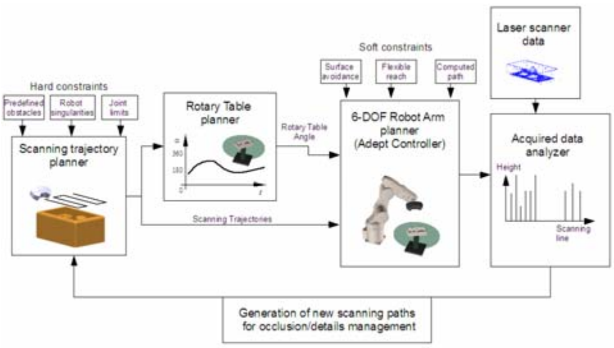


Figure 6. Planning based on motion constraints during the constituted process of scanning up

For the proposed constructive solution have been developed more software:

- software for correlation of the scanner with the robotic arm;
- trajectories generator software;
- software for the movement of the rotary table in the scanning process;
- software interface with the user;
- Scanning and digitizing software.

The degree of similarity for some measurement for a piece from automotive industry (differential box) controlled in 3D with the mechatronic laser scanning device is very high as we can see during the scanning process and comparison with original parts in CAD format (left) in figure 7.

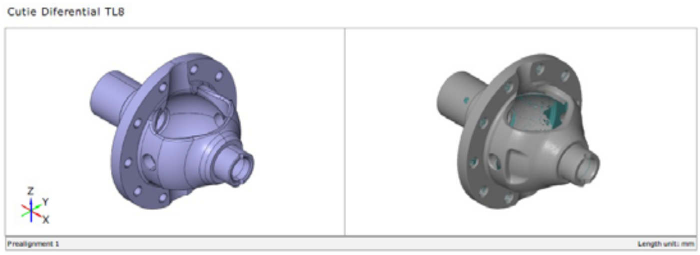
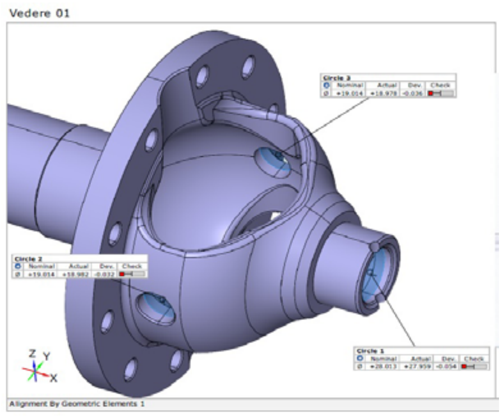
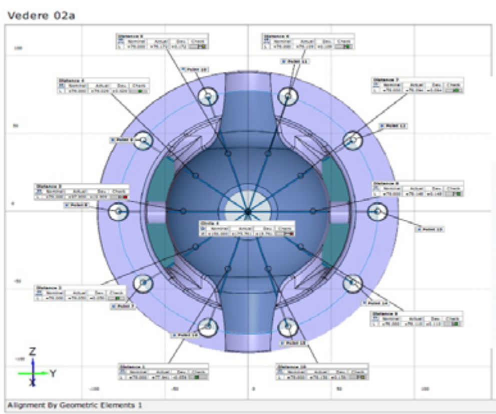


Fig. 7. Similarity from scanning result and CAD part

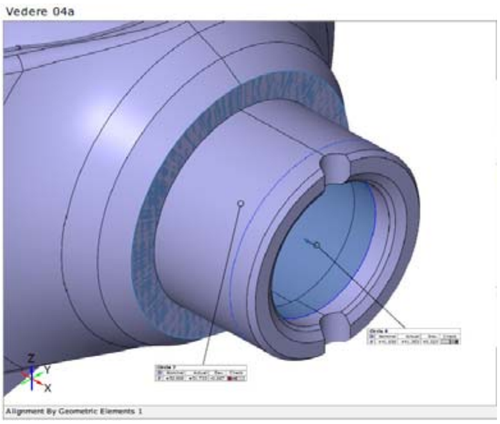
The number of measurements that can be done using the measurement software after the digitization of the point cloud and the reproduction of part in three-dimensional format after the scanning operation with special software are numerous and varied (Figure 8) [10].



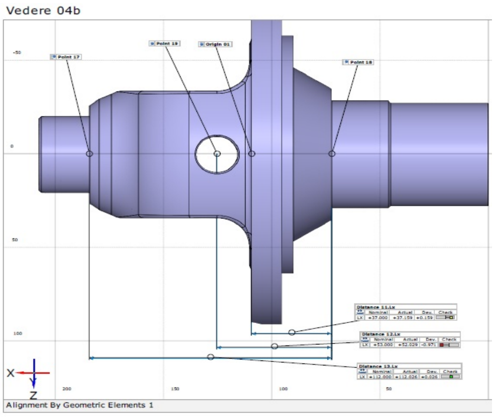
a.



b.



c.



d.

Fig. 8. Various types of measurements

4. CONCLUSIONS

Today the life cycle of products is getting shorter, practicing economies of scale or internalization of the various activities are not always available to everyone, and consumer demands (of the exploiters) that concern characteristics and quality of products have increased and diversified. However, from a technical and economic vision we felt the need of standardization in most industries. In this context, man and machine are so determined to build increasingly more economical, faster, and safer at the same time. Control is required to participate in all stages of developing a product from conception to operation, maintenance or recycling [10].

The accuracy is the most important parameter of the 3D scanning technique and he is dictated by the purpose of the application. Because the automotive industry requires a high degree of accuracy, we use only high-tech mechatronic systems for integrated 3D control with non-contact laser sensors and we need a fairly high threshold of the data quality, the tolerances accepted in most cases being between ± 0.001 mm and ± 0.01 mm.

The 3D scanning techniques and those of rapid prototyping play an important role in the reverse engineering techniques in the automotive industry, even if such a procedure does not necessarily assume physical realization of the prototype. Using the high-tech mechatronic 3D laser system for integrated control, a prototype can be made and approved, followed by changes and the realization of a 3D model that can be made quickly and easily, all these in one day [2].

The scanned data can be transferred to any CAD file format and is accessible to a large number of equipment. After a product has been made, it can be scanned and the resulting data can be compared with the geometric patterns and the errors can be precisely determined. Once the object is in electronic format by scanning, the complex ideas and the changes can be applied easily and accurately without making again the physical model. The manufacturing processes can be developed in several establishments of the same company or in different locations around the globe [9].

In our country, although some progress has been made in upgrading equipment and technology, the use in multiple industries of some outdated technologies and equipment, high consuming of energy and raw materials, has led to drastic reduction of productivity in these sectors, where high tech industries are underdeveloped or nonexistent.

REFERENCES

1. N. A. Mihai, "Optimization of assembly technologies in the automotive industry", PhD. Thesis, Transilvania University, 2011.
2. K. Lkeuchi, "Modeling from Reality" in *3rd International Conference on 3-D Digital Imaging and Modeling: proceedings,* Quebec City, Canada. Los Alamitos, CA: IEEE Computer Society, 2001, pp. 117–124.
3. Gh. I. Gheorghe, D. D. Palade, V. Pau, F. I. Popa , *μSensorics, Mechatronics and Robotics*, Bucharest: Cefin Publishing House, 2004.
4. S. Larsson and J.A.P. Kjellander, *Robotics and Autonomous Systems* 54, 453-460 (2006).
5. A. lark – Vasilescu, Industrial Metrology - Volume II - Applications in the Field Length - Documentation Proser & Printech, Bucharest - 2006.
6. Z. Song, H. Peisen, Optical Engineering 45, 123601 (2006).
7. Gh. I. Gheorghe, S. Istrițeanu, V. Despa, Al. Constantinescu, A. Voicu, Mechatronics, Integronics and Adaptronics, Bucharest, Cefin Publishing House, 2012.
8. T. Peng, "Algorithms and models for 3-D shape measurement using digital fringe projections", Ph.D. Thesis, University of Maryland, 2007.
9. F. Blais, M. Picard, G. Godin, "Accurate 3D acquisition of freely moving objects" in *2nd International Symposium on 3D Data Processing, Visualization, and Transmission,* Thessaloniki, Greece. Los Alamitos, CA: IEEE Computer Society, 2004, pp. 422–429.
10. Gh. I. Gheorghe, M. Vocurek, P. Beca, Current status and perspective of integrated automatic control of technological processes with intelligent complementary trends in Europe, CEFIN Publishing House, Bucharest, Romania, 2010.
11. Industrial competitiveness of EU member states: some progress made, but many challenges still lay ahead European Commission - MEMO/13/816 - 25/09/2013.