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OPTICAL COORDINATE MEASUREMENTS OF PARTS AND ASSEMBLIES IN AUTOMOTIVE INDUSTRY

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Professional paper

Photogrammetry is a technique of measuring 3D coordinates using photography as the main medium of metrology. This paper describes the use of the photogrammetric system in the automotive industry for control and measuring tasks. This contactless method is suitable for industrial application, because the measuring instruments are robust and mobile, so precise measurements are possible in production conditions. Presented results of measurements show that the optical measuring systems are powerful tools for quality control, analysis and discovering of causes of faults.

Keywords: *accuracy; automotive industry; optical measurement; photogrammetry*

Optička koordinatna mjerenja dijelova i sklopova u autoindustriji

Stručni članak

Fotogrametrija je tehnika merenja 3D koordinata koja koristi fotografije kao osnovni metrološki medij. U radu je prikazana primjena fotogrametrijskog sustava na mjernim i kontrolnim zadacima u automobilskoj industriji. Ova beskontaktna metoda je pogodna jer su mjerni uređaji robusni i mobilni, pa su precizna mjerenja moguća i u proizvodnim uvjetima. Prikazani rezultati mjerenja pokazuju da su optički mjerni sustavi moćan alat za kontrolu kvalitete, analizu i otklanjanje grešaka.

Ključne riječi: *autoindustrija; fotogrametrija; optičko mjerenje; točnost*

1 Introduction

Optical measuring devices offer numerous advantages in comparison to the classic methods of quality control in automotive industry such as tactile measuring systems. Optical measuring systems can be used to measure complex geometry and generate large point clouds which represent observed geometry [1, 2]. Optical measuring systems are portable and robust, so measuring is not limited to laboratories, but it is also easily done in the field [3]. Optical measuring systems are non-contact and non-destructive and thus do not influence measured object [4]. In recent years, optical measuring systems are being intensively used in the automotive industry [1, 3, 5]. Good interfaces to major CAD/CAM systems made possible for these digitalization systems to be part of complex production chains. Using optical measuring systems significantly reduces time required for product development and increases product accuracy.

Optical 3D digitalization systems are used in quality control, reverse engineering and rapid prototyping [1]. Data obtained from these systems are used for 3D visualization and deformation analysis [6]. Wear of cutting tools can be monitored using an optical device for 3D surface measurement [2, 7]. Repeatedly digitizing objects through time and comparing results is used for monitoring damage occurrence and helps in planning and preparing repairs [2]. This technology is particularly useful in automotive industry for production and optimization of tools, monitoring of production process, control of input parts, control of assembly quality and zero series quality control [3].

Optical measuring systems can process 3D shape of entire object in detail, or certain parts of great importance [8]. Depending on analysis type and desired results, the deviation of digitalization results in comparison to the CAD model can be determined; control of shape and position tolerances can be performed. Final product shape can be compared with prototype or specimen, or used as digitalized part for virtual assembly [1].

Complex measuring results require adequate documentation for further use by workers with different level of technical education. For that purpose GOM software has built-in functions for creation of measuring reports. The system can be configured according to the specific needs of different measuring tasks.

Results of digitization performed by optical measuring systems ATOS and TRITOP represent polygon mesh or point cloud (with up to several million measuring points) [2]. Also, results of digitization may be in the form of cross sections, the characteristic lines or geometric entities [9]. Supported formats for data export are C3D, G3D, STL, POL, IGES, VDA/PSET, ASCII, PLY, etc.

Photogrammetric systems provide precision that matches precision obtained with systems for coordinate measurement with high precision in large volumes such as digital theodolites, coordinate measuring machines (CMM), laser trackers and other systems [1, 3]. Precision of photometric measuring can vary significantly depending on several interconnected factors. The most important factors are quality and resolution of camera used for measuring, size of object that is being measured, number of photographs taken, and layout of photographs in regard to object as well as in regard to other photographs.

2 Principles of photogrammetric and triangulation

Photogrammetric is a technique of measuring of 3D coordinates which uses photographs as a basic metrology medium [10]. Triangulation is the method used in photogrammetric for obtaining 3D coordinates of points.

Photogrammetric measurements are dimensionless, so photograph contains no information about size of photographed object. If the object with known size is placed in volume that is being photographed, more complete information about characteristics of measured object is obtained [3]. Photogrammetric measurement requires at least one known length placed in photographed volume [3]. If real coordinates of some reference points are known, their distances can be determined and used for dimensioning of the measured object. The other possibility is using reference points with constant distances, in the form of measuring reference scale bars which are placed in photographed volume (Fig. 1) [3, 11].

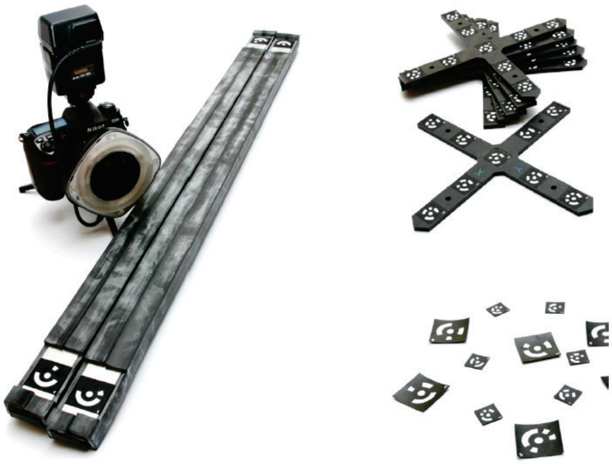

Figure 1 Photogrammetric system TRITOP (DSLR camera, reference scale bars, reference crosses and coded reference points)

Distance between reference points is obtained by high precision measuring machines, and scale bars are made of alloys that have a negligible coefficient of linear expansion in certain temperature span. For measurement dimensioning more than one known distance should be used. Length of scale bars should match object dimensions. Every imprecision of reference lengths is then multiplied with ratio between measured object dimension and reference length. For example, if reference measurement 1 meter scale bar is used for measuring object that is 10 meters in length and reference length is manufactured with 0,1 mm error, then the measured object will have 10 times greater error, 1 mm in this case.

If these photographs are taken from at least 2 positions so called "visibility lines" from camera to point on an object can be created, Fig. 2 [5, 10].

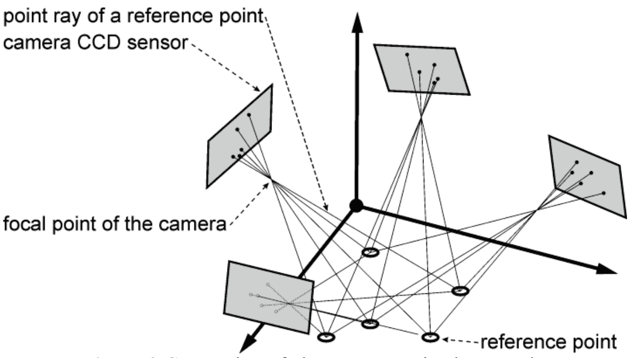

Figure 2 Connection of photogrammetric photographs

The very precise position of point in space can be determined using mathematical intersection of lines. [5, 10]. Photogrammetric measuring devices can measure positions of multiple points simultaneously, while the only limiting factor for the number of points is hardware performance [11].

Calibration of equipment is required for quality measurement [12]. Calibration is process during which measuring system, with or without a calibration object, performs self adjustment to ensure accuracy of measurement. Every time optical measuring system TRITOP is assembled, it has unique and unrepeatable configuration. Characteristics of the components of the system are changed over time, and light conditions are different at different positions of measurement. Possibility of camera to be calibrated as one of the components of the measurement process (making photographs) is called self calibration. The camera is calibrated during measurement according to the environment variables (temperature, humidity, etc.) that are present during measurement. This is a significant advantage in comparison to the systems that are calibrated in laboratory conditions, since laboratory conditions can be very different from conditions at measuring location [3]. TRITOP system requires taking 4 starting calibration photographs, from the same position and in the same direction, while rotating the camera by 90° after each photograph. If self calibration is not performed, predefined calibration is used resulting in less reliability and precision.

Top quality photographs are required for full utilization of system possibilities and for making quality photogrammetric measurements with high precision and reliability. Three most important parameters for a good photogrammetric photograph are: viewing angle, focus, exposition. These parameters must be taken into account during the process of object preparation, which will be discussed in detail in the next section.

3 Object preparation and performing photogrammetric measurement

No matter what measuring type, every measuring process consists of the following steps: planning of measurement, preparation of measurement, making measuring photographs, project creation, photograph processing, analysis and documentation of measuring results. These are common phases for all projects. Every measurement has its own specifics and content, and sometimes order of these steps needs to be altered.

In order to do quality photogrammetric measurement, the following conditions must be satisfied:

- Object volume must be the same order of dimension as available reference scale bars (Fig. 3 shows clearance between front and rear door to be approximately the same length as the used reference scale bars),
- Before actual measurement, calibration photographs should be made,
- On every photograph used in photogrammetric measurement, software needs to identify at least 5 previously photographed coded reference points, so it could be possible to orientate photograph in a common coordinate system,
- Every un-coded reference point should be visible in at least 3 photographs, in order to calculate its position based upon coded reference points.

Figure 3 Right side of car prepared for door clearance control

Adapters enable determination of 3D coordinates for the following elements: centre of circular openings and holes, centre of the sphere (if the diameter of the sphere is known or its measuring is possible), cone, cylinder axis (if the diameter is known and the point defined by a cross-section between the rotation axis and a plane perpendicular to the axis), edges and clearances, planes. TRITOP adapters have un-coded reference points for identification in TRITOP software. Adapters that have only one reference point are used for measuring 3D coordinates of circular openings and holes, while adapters with multiple reference points are used for determination of other elements listed above.

When preparing objects for measuring, special attention must be paid to ensuring that a measured object is properly transformed into the vehicle's coordinate system. Every piece of tool and equipment for the montage and control of sub-assemblies and assemblies of car body has attached reference spheres whose coordinates are known in vehicle coordinate system, Fig. 4.

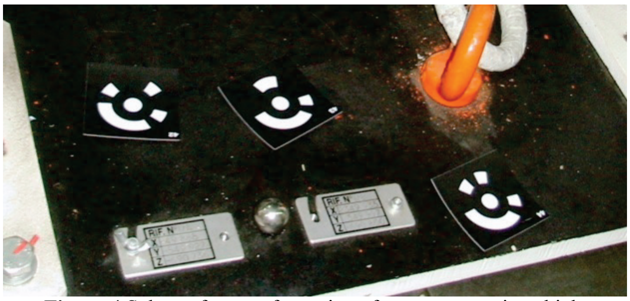

Figure 4 Spheres for transformation of measurement in vehicle coordinate system

If adapters for spheres are placed, with known sphere diameter, software can determine the sphere centre. Transformation of measuring project (position of cameras, reference objects, photographed un-coded points) is performed by inputting coordinates of sphere centres that are attached to tools and equipment. Four transformation spheres are attached to every piece of the tool and control equipment so it is possible to determine error for every transformation.

All adapters with multiple reference points have unique placed reference points (with relative position data in .adp file), so that TRITOP software can identify them on its own. These adapters are marked with serial number which is also included in .adp file. All adapters with multiple points are given matching basic primitives which are created automatically in the software after identification of adapter.

Hole adapters play important role in measuring project. These adapters have a shape of half-sphere with known diameter, with un-coded reference point located in their centre. Hole adapter represented in software consists of plane and a point obtained by projecting reference point of the adapter to that plane. This means the plane in which opening or hole is located needs to be defined, by placing points (at least 4 of them) in the vicinity of the opening or hole. Fig. 5 shows engine cage of car with properly placed hole adapters.

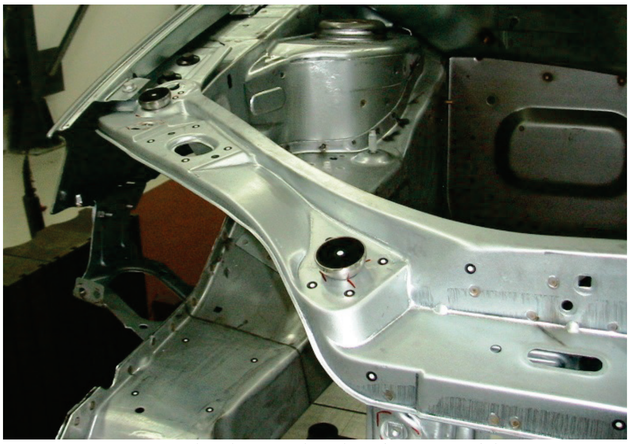

Figure 5 Hole adapters placed on front part of the car

Adapters can be moved during measurement. For them to appear in a measuring project, at least 4 photographs must be made. These 4 photographs will be used by software to place adapters in the appropriate position in coordinate system common to all photographs.

After the object is prepared, photogrammetric measurement is conducted by the photographing measured object. At the beginning of the measurement, 4 self-calibration photographs are made while the camera is placed over a measured object and the entire measured object and reference scale bars are visible by the camera. Other photographs are made from at least 2 heights, circling around measured object.

4 Application of photogrammetric measurement system for assembly quality control and results of measurements

Fig. 6 shows nominal and real coordinates of spheres used for transformation into vehicle coordinate system, as well as corresponding deviation [5]. These spheres, which are used for reference point system (RPS) transformation, are shown in Fig. 4.

The Rear suspension bracket is an assembly made of 3 sub-assemblies. Their centring on tools is done by 4 jigs. Jigs 2, 3, 4 constrain assembly in *X* and *Y* directions while jig 1 constrains assembly in Z direction. Fig. 7 shows the positions of jigs obtained by measurement as well as deviation in comparison to the positions defined by documentation.

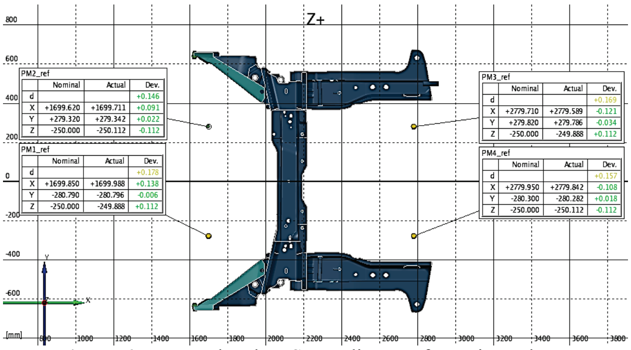

Figure 6 Measured and RPS coordinates of centring spheres

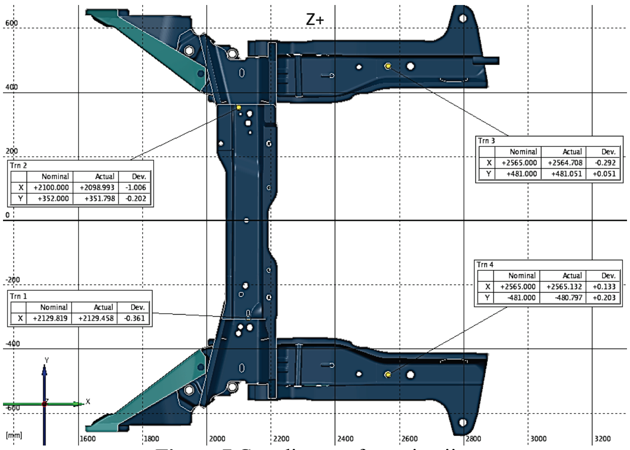

Figure 7 Coordinates of centring jigs

Accuracy is one of the most important parameters that influence final product quality. The control of tools for montage, welding, cutting or pressing, requires validation of the positions of all supports, whose task is to properly position sub-assemblies in relation to each other as well as in relation to the vehicle coordinate system [5]. For determination of current position, un-coded reference points are placed on support surfaces, on which pressings are placed. Figs. 8 and 9 show positions of some supports and their deviation in comparison with the CAD model.

Process of tool adjustment is iterative, so it is sometimes necessary to repeat the measurement several times, in order to place fixation elements in positions within tolerances given by the documentation. As a result of 3D digitization point cloud is obtained, which describes in detail complete geometry of elements and the entire assembly [2, 1].

Fig. 10 shows point cloud obtained by 3D digitization of rear axle suspension bracket assembly.

This cloud consists of 1 325 455 points, with 0,01 mm distance between points. The size of the project for digitization and analysis of the results is 1,12 GB which is enough to describe configuration of digitized object with great accuracy and with high level of detail (Fig. 11).

The reduction of the number of points is performed by the built-in algorithms, when individual measuring are overlapped during the process of point cloud and polygon mesh creation [1]. This reduction means keeping every or every other point on curved surfaces, and every fourth or every eight point on flat surfaces. This way no information about configuration of digitized surface is lost.

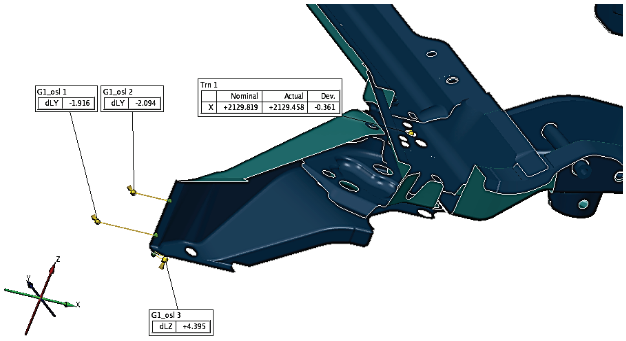

Figure 8 Deviations of tool parts used for constraining of rear axle suspension bracket in comparison to the CAD model

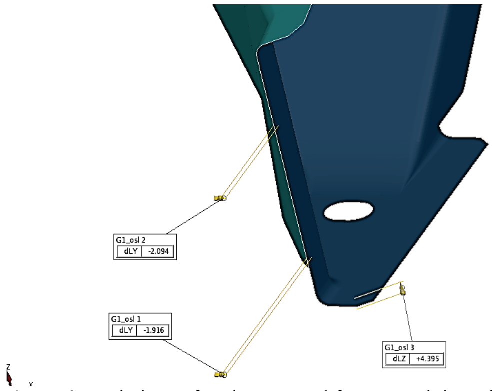

Figure 9 Deviations of tool parts used for constraining of rear axle suspension bracket in comparison to the CAD model

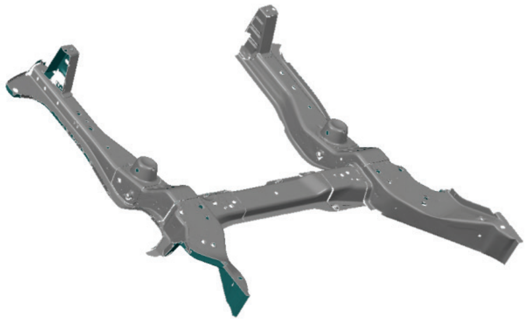

Figure 10 Result of part digitization

Figure 11 Detail of digitized part

Point obtained by the process of optical digitization is placed in the coordinate system defined by the first individual measurement. Since the position of the digitalized model in this coordinate system is random, registration needs to be performed, that is, transformation of obtained model in vehicle coordinate system. There are many methods for this process, and in this paper Best fit method is used [2],[10]. This method means that the software places digitalized model in such a manner that deviation from CAD model is minimized.

The user creates basic primitives, points, lines, planes, spheres, cones from transformed and polygonized mesh. By definition of circle centres, for example, real positions of centring jigs on the manufactured welded assembly can be determined (Figs. 12 and 13) and installation or possible corrections of tools for a montage of rear axle suspension bracket analyzed.

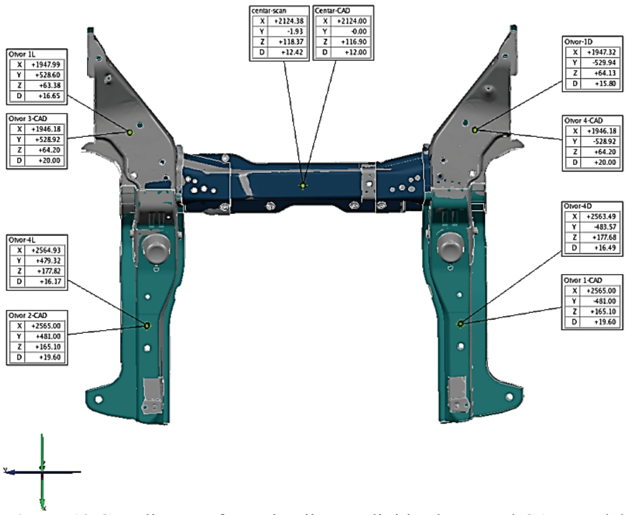

Figure 12 Coordinates of centring jigs on digitized part and CAD model (Best Fit registration)

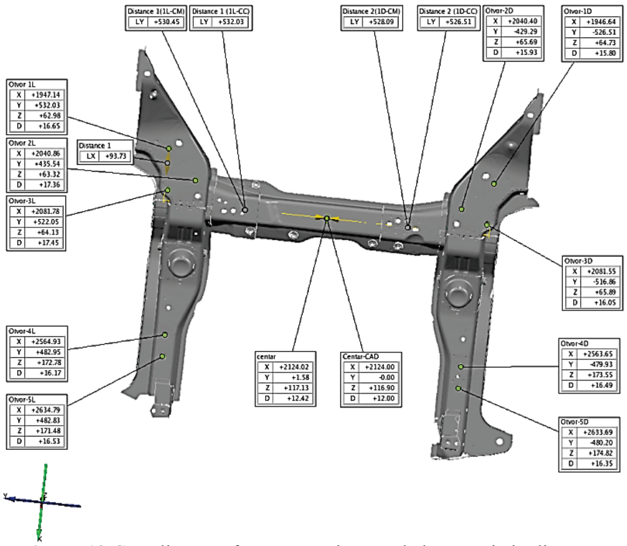

Figure 13 Coordinates of some openings and characteristic distances

5 Conclusion

When high accuracy of large amount of data is needed in a short time period, speed and flexibility of 3D digitalization systems come into play. Influence on measured object is negligible due to gathering data without contact. Since measurement technique is based on photographs, results can be easily and intuitively presented.

These systems can work with wide size ranges of measured objects (from a few millimetres up to dozens of meters) which gives them a great advantage in comparison to state of the art conventional systems. For example, it is possible to perform quality control of large objects (chassis, trucks, lorries, tippers, busses, military vehicles and weapon systems). Usage of such 3D digitalization systems is many times cheaper than the usages of tactile coordinate measuring machines. Aside from this main function these systems can perform a determination of static and quasi-static deformations.

Usage of optical measuring systems ATOS and TRITOP enables easy creation of typical measurement reports (correct or incorrect) which are common to conventional measuring systems. Detailed optical 3D digitalization also provides a lot of additional information, which makes it easier to find the cause of inaccuracy and to optimize production. Typical application in sheet metal processing, cast metal or cast plastics includes checking and improvement of tools and gadgets, control of prototype and test series shape and production optimization. Periodic control of samples using 3D digitalization system ensures the quality of serial production as well as full automation of the series control for especially demanding products.

Photogrammetric measurement of tools used for the montage and welding of rear axle suspension bracket and optical 3D digitization of manufactured assembly is used for creation of precise computer models. This enables analysis of the current state, discovering of causes of faults formation and gives the possibility for optimization and planning corrections in order to obtain assembly that meets demands defined by technical-technological documentation.

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