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3D MEASUREMENT - COMPARISON OF CMM AND 3D SCANNER

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Abstract

Continuous improvement and optimization of products, which is the most often reflected in more complex geometrical and dimensional characteristics of products and increasing market demands for quality, lead to the development of new solutions in quality control. In industry today, the control of geometric characteristics is most often performed by the tactile method of probe stylus, i.e. using 3D coordinate measuring machines (CMM). Coordinate measuring machines have long been the only option in quality control of various products and have become generally accepted in industrial quality. In recent years, the development of digital technologies, i.e. the development of a new generation of hardware and software, has enabled the development of other methods of 3D measurement such as 3D scanner, which has proven to be a good alternative to CMM machines. The aim of this review is to provide insight into the areas of application of both devices as well as their advantages and disadvantages and possible future solutions and application of devices in this area.

Keywords: Quality control; 3D measurement; Coordinate measuring machine (CMM); 3D scanner

1. Introduction

With the development of technology, there has been a revolution in production. Increasing the capabilities of machines has led to an increase in demand for functional and aesthetic properties of products on the market. Also, increased competition in the market has led to the optimization of product performance, which has resulted in increased requirements for the accuracy of manufacturing parts and reducing the allowable tolerances of products. All these requirements are built into the quality of the product itself. Throughout history, the view of quality has changed, from the period when manufacturers imposed quality standards, until today where the market or customers determine the basic requirements for quality. Due to the complex requirements of the market and increasing competition, the need for quality control is growing, and due to its importance, it is in every part of business processes. Thus, it is now present in the production process of individual parts or immediately after it, and not only after the completion of the complete product. All these requirements have shaped new methods and quality control procedures. This paper will deal with 3D measurement procedures, which are indispensable in manufacturing companies, whose products must meet dimensional and geometric tolerance requirements. Until today, the most common method of 3D measurement is the contact method, which is based on the correct contact detection of the measuring sensor with the measuring surface. In this way, information on the measuring point position on the surface of the measuring object is obtained. Due to this basic concept where physical contact must be made for each measuring point, with the production development and deadlines shortening, methods have become too slow in the field of quality control. Also, the contact methods discretization and the amount of obtained information encouraged the development of more efficient methods [1].

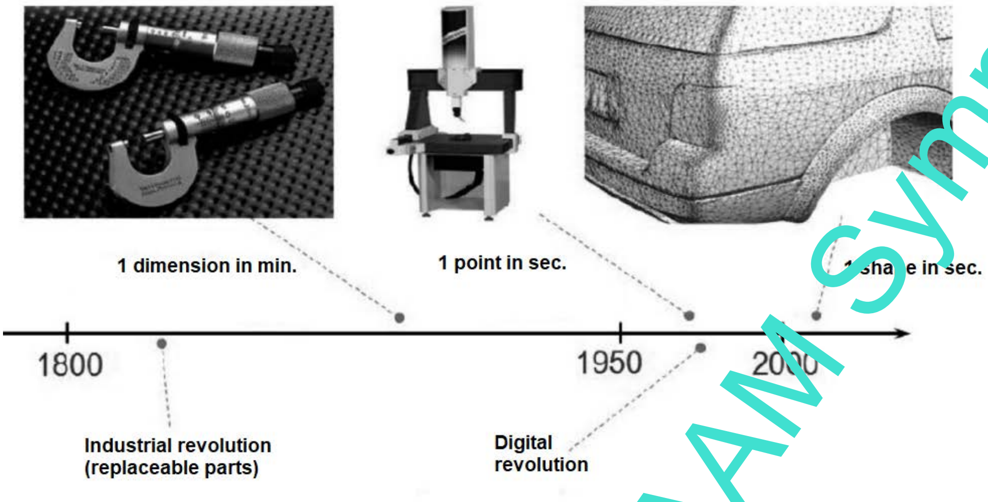

Fig. 1. Historical development of object measurement

With the development of technology in the 1980s, contactless 3D measurement procedures appeared. Thus, the aim was to speed up the measurement process as well as to avoid physical contact. The most common method is optical measurement via a 3D scanner´s, where the measuring point position is defined by projecting structured light onto the measuring object surface (e.g. 3D digitizer). The 3D scanner basic features, such as faster measurement with acceptable accuracy and the ability to digitize the measured object, make this method very suitable in today's conditions of production and quality control. When measuring small parts, optical measuring systems are very effective. For example, using of active triangulation scanning technique for shape investigation of worn cutting inserts, measurement of wear process of milling tool based on optical method, dimensional analysis of cutting inserts using optical multisensory device. Another research have been made for instance in the field of 3D reconstruction of small objects from a sequence of multi-focused images, or an example of application of optical scanning in the Reverse Engineering process with additive manufacturing - Rapid Prototyping [2].

The ability to generate 3D models based on multiple images makes this method very suitable for reversible engineering, which is unavoidable in all major manufacturing companies (e.g., the automotive industry). These are some of the main reasons for the growing need for optical 3D digitizers in the quality control process. The advantage of optical measuring devices is in the amount of information obtained because of digitization and in the reduction of the time required for measurement as well as in the economic justification in relation to CMM. The aim of this paper is to provide an overview and contribution to the understanding of existing and new technologies in the field of 3D metrology, which is increasingly used daily in product quality control and is being improved.

2. Three-coordinate measurement methods

As already mentioned, the end of the last century and the beginning of the 21st century represent a development time of many three-coordinate measurement methods. Therefore, in this chapter, we will present the classifications of three-coordinate measurement methods. Most often, the classification of measurement methods is based on the definition of the measurement point. These methods follow two basic directions: passive and active [3].

The development of active measurement methods has been much more productive than the development of passive measurement methods (Figure 2), but recently more importance has been given to the development of passive measurement methods [4]. The main reason for the significant development of passive methods is the need and increasing demands for machine vision.

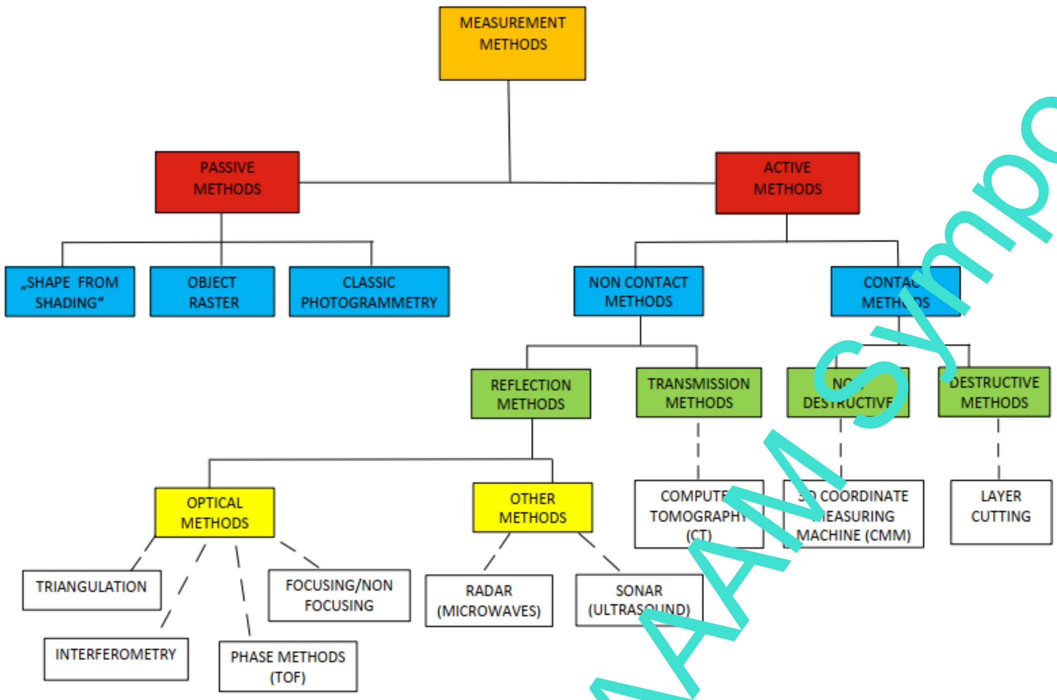

Fig. 2. Measurement methods division according to the method of measuring point definition [4]

An additional advantage of passive measuring methods is that they do not require an additional external energy source to define the position of the measuring point but use existing or subsequently applied markings on the measuring surfaces. The epilogue to this is that today passive systems are usually cheaper than equivalent active measuring systems [1].

2.1. Passive measurement methods

Passive measuring methods are suitable for time tracking of the measuring point position concerning the coordinate system in which the measuring object is located because they do not need physical interaction of the measuring sensor with the surface of the measuring object. They use existing or subsequently applied geometrically correct or stochastic markings on the measuring object surface and optical laws to obtain measurement information. This is achieved by analysing the reflected light from the measuring surface to obtain information about the relative spatial position of the measuring points on the surface of the measuring object in the current configuration. In passive methods, daylight or artificial light can be used as a light source. It is important that the light source does not actively participate in the definition of measuring points but only allows their visibility to the measuring sensor [1].

Fig. 3. Passive optical measuring systems (TRITOP, ARAMIS, PONTOS) [1]

2.2. Active measurement methods

Unlike passive, active measurement methods use additional mechanical tentacles or optical projection methods to solve the problem of unambiguity. Projection methods are controlled projections of encoded coherent or incoherent light. They are widely used in the industry. The measuring point position is actively defined, relative to the measuring sensor, regardless of the optical and geometric characteristics of the measured surface. In contact active measuring methods, the measuring point position is defined by direct contact of the mechanical sensor with the measuring surface (e.g. three-coordinate measuring device), while in non-contact active measuring methods this is achieved by projecting structured light on the measuring object surface (e.g. 3D digitizer) [1].

Fig. 4. Measuring devices based on the active measuring method (CMM Erowa, 3D digitizer ATOS) [1]

3. Coordinate measuring machine (CMM)

The coordinate measuring machine (CMM) belongs to the group of contact measuring devices. The first CMM device was developed by the Ferranti Company in Scotland, in the 1950s, due to the need for more accurate measurements of military equipment components and had only two coordinates. More intensive use of multi-coordinate (three-coordinate) CMM devices was achieved about 20 years later, i.e. after connecting the device to a computer. With modern CMM devices computer takes over the processing of measurement results and controls the entire measurement process. From the moment of their appearance, intensive development of CMM has been recorded, all to comprehensively ensure the fundamental advantages that three-coordinate measurements can provide. A coordinate measuring machine is a measuring system used to measure coordinates in space on the surface of the measuring object, which can be software converted into dimensional and geometric characteristics such as lengths, angles, geometric shapes, deviations of the position, etc., including roughness of technical surfaces. That is, the principle of operation of the CMM device is based on feeling the measured object using a measuring probe. The probe moves along the Cartesian (XYZ coordinates), polar and cylindrical coordinate systems. Each axis has its sensor, which monitors the exact location of the probe on that axis with micrometre precision. When the probe touches the object's surface, the tactile CMM collects data from all three sensors and creates a "point cloud" which describes the needed surface of the object [5].

Coordinate measuring machines (CMM) represent one of the most accurate and flexible measuring instruments used in the metrology field. These are the main reasons why they have become widespread throughout manufacturing companies. Therefore, with this kind of measuring device, it is possible to carry out measurements with a high degree of precision for manufactured parts of practically any type of shape and size [6].

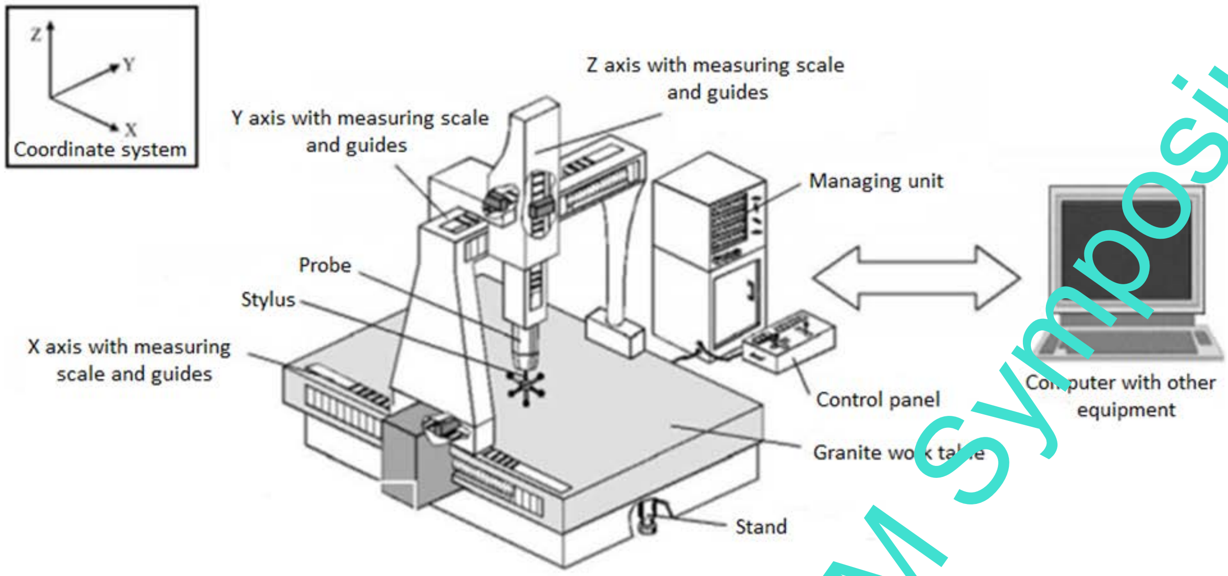

Fig. 5. Coordinate measuring machine (CMM) [10]

Today, there are several different configurations of this device, such as bridge design, column design, cantilever, horizontal arm device, mobile stand device, etc. Different CMM configurations prove the wide application of this device in the industrial measurement of various objects, from very small pieces the size of a few millimetres (e.g. thread measurement) to larger objects size of several meters (e.g. measuring the dimensions of a complete car). The basic component of a CMM device is a tactile sounding system, which must at least meet the following requirements:

- a touching element to establish an interaction with the workpiece (e.g. tip ball)
- a transmitting device to transfer information about the interaction from the touching element to the sensor (e.g. stylus shaft)
- a force generating element (suspension) to produce a defined probing force (e.g. spring)
- a sensor to sense the interaction of the touching element with the workpiece (e.g. electric switch)
- an output transmitting the information for triggering a length measuring device (e.g. scale) or for further processing (e.g. correction of bending taking into account qualified tip ball radius, evaluation in instrument's software) [7].

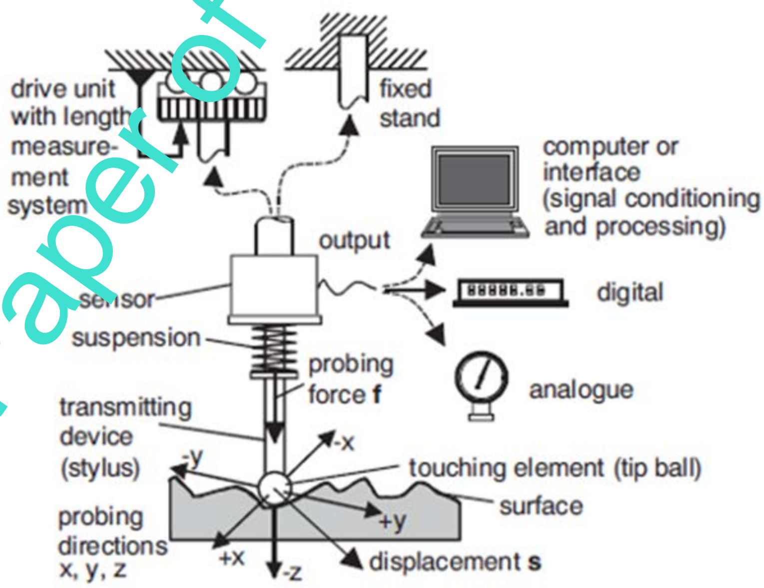

Fig. 6. Probing system basic configuration [7]

Measuring the position of the top of the ball is more reliable if it is carried out as directly as possible. The main reason is that the transmission elements cause additional deviations, so it is recommended to use transmission elements as simple as possible (with fewer components). Also, the distance between the contact point with the measuring object and the sensitivity point of the sensor must be as short as possible. For optimal dynamic measurement performance, the mass between these two points should be as small as possible. Therefore, for precise measurements, it is necessary to choose the shortest stylus with the highest possible stiffness, and also unnecessary connecting elements should be avoided. The measurement process should be controlled and constant in terms of environmental measurement conditions. Also, measuring instruments and the object of measurement should be harmonized with the environmental conditions in which the measurement will be performed before the measurement process. Standard metrological conditions are: temperature T = 20 °C, air pressure p = 101 325 Pa and relative humidity R = 58 %.

4. 3D scanner

Another method that is successfully used in 3D measurement is the non-contact measurement method. The basic features of the non-contact measurement method, such as faster measurement performance, acceptable accuracy, and the possibility of digitization of the measured object with the software solutions support, make it very suitable in reversible engineering. It is a procedure, which, based on the measurement results (point clouds) of the object, generates a CAD model of the observed object. In the literature, 3D digitizers are often referred to because of the ability to digitize measured objects. The needs of the industry are most responsible for the development of 3D scanners, of different purposes and characteristics. Among the industries, the automotive industry is certainly at the forefront, where the requirements for faster digitization of measured objects and a larger amount of collected information have greatly increased. Today, there are many non-contact measuring devices on the market, which are optical measuring devices the most common. According to the definition method (coding) of the measuring point position on the measuring object surface relative to the measuring sensor, there are:

- triangulation systems,
- amplitude and phase modulated TOF systems (Time of Flight Measurement) and
- interferometric projection systems.

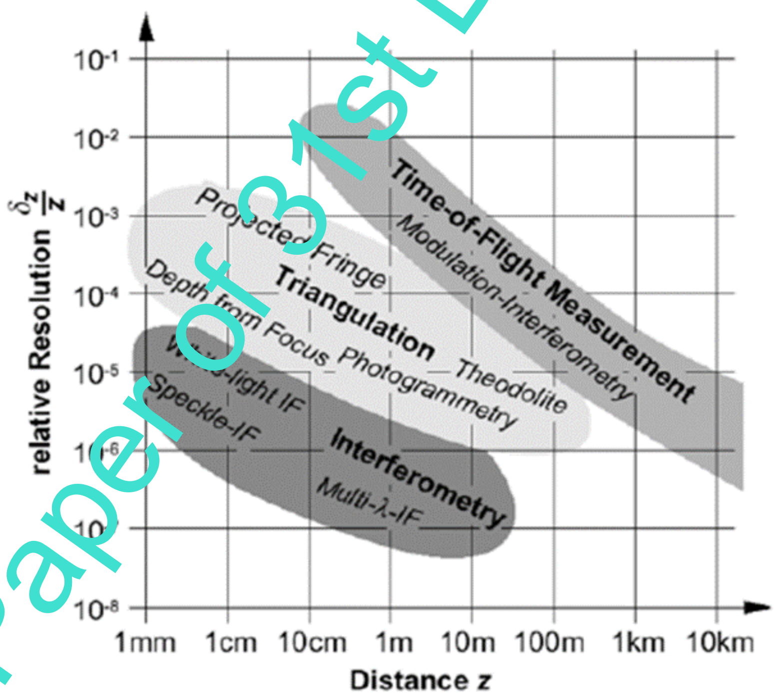

Fig. 7. Performance of different optical D ranging system [8]

4.1. *GOM Atos*

Due to many different types of 3D scanners, it is almost impossible to process all types in this paper. Therefore, we will pay the most attention to the GOM ATOS group of optical 3D scanners, which are one of the most common scanners on the market that are based on the triangulation measurement method. The GOM ATOS coordinate measuring system is a stereoscopic system based on two measuring cameras. Moreover, the system still consists of a projector, a tripod, the control unit and a computer scanner. Schematic of measuring system with rotary table and a view of a measuring station is shown in Fig. 8. [9].

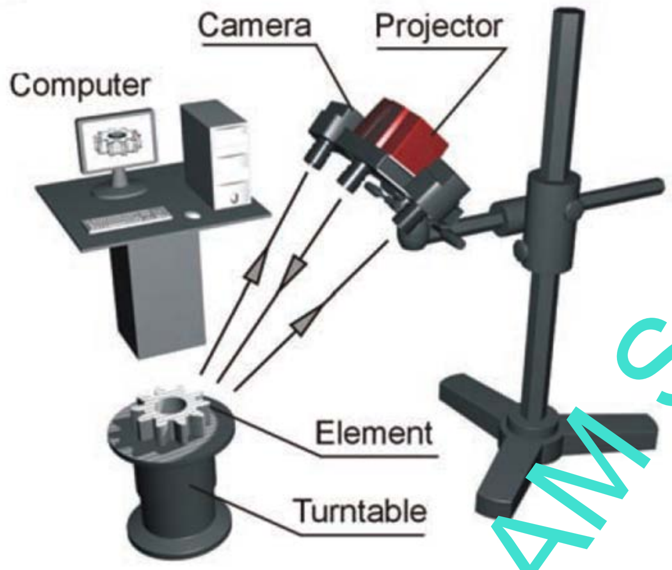

Fig. 8. GOM Atos compact scan [9]

Before the measurement itself, it is necessary to prepare the measuring object. Preparation involves the optical system calibration using a calibration object. Calibration ensures the dimensional stability of the measuring system. It consists of recording the images in various distance, position and orientation of each camera in relation to a calibration object clamped on a rotary table. As a result, the characteristics of the camera lenses and chips were determined. Based on these data, software calculated 3D coordinates from the points of the calibration object in the 2D camera. [2].

The next step involves gluing markers that represent reference points during the scan and applying an anti-reflective coating (e.g. titanium powder) to the reflecting surfaces. Markers i.e. reference points are the basis for determining the coordinates of the measured object and the number of required markers depends on the size of the test piece. There are set parameters of digitization. Camera focus and the projector focus as well as the polarization filter for camera are adjusted for the best contrast of measured object surface. The full resolution, normal exposition time as well as high quality of scan are adjusted. Position, angle and number of rotations of the chuck with clamped measured object situated on the rotary table in relation to measuring space, are set. Subsequently, digitizing is performed. Consequently, another steps are set, like deleting redundant scanned features and objects (e.g. chuck), standard mesh polygonization and postprocessing with more details. As a result from these steps the digital model of the measured object in the STL format is exported [2].

5. Conclusion

Through this paper, an insight into the existing methods and devices of 3D measurements is given, which today represent the basic dimensional control of modern metrology. After reviewing the literature, it can be concluded that today there is a large range of different measuring methods and devices on the market, of which the most common are CMM contact and optical non-contact devices. Although the coordinate measuring machine (CMM) is considered to be the standard in metrology, optical non-contact measuring devices are a revolution in the application of dimensional verification of objects and in Rapid Prototyping, because of faster measurement, the possibility to measure flexible materials and to measure directly on the machine. The scanner allows you to measure the entire object surface, even those with very complex shapes. Measuring accuracy for these devices depends on the applied optical system and resolution of the measuring matrix. The limitation for the optical scanner is the lack of the measurement possibility of internal surfaces (such as deep holes and grooves) and lower measuring accuracy than for CMM.

Experiments conducted and processed in [11] indicate that there are differences and measurement deviations, although negligible, and it is necessary to work on further research of accuracy and monitoring of environmental measurement conditions, selection of approximation methods to increase the accuracy of 3D scanning procedures. Finally, the measurement method selection depends on the measurer, his knowledge of different methods and devices, and the economic justification of the chosen method.

Future research will provide further understanding and contribution in the field of 3D measuring devices. With the application of new digital technologies and software solutions, it will be possible to implement the measuring and controlling process of the products and prototypes quality even faster.

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