3D MEASURING OF COMPLEX AUTOMOTIVE PARTS USING VIDEO-LASER SCANNING

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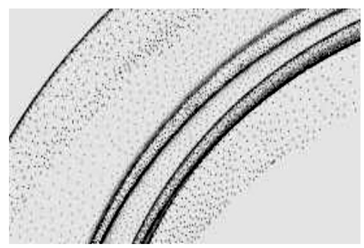
Abstract. *Three-dimensional scanning is available for more than 15 years, however there are few that have heard of it and as few people know the applications of this technology. 3D scanning is also known as 3D digitizing, the name coming from the fact that this is a process that uses a contact or non-contact digitizing probe to capture the objects form and recreate them in a virtual workspace through a very dense network of points (xyz) as a 3D graph representation. Most automotive manufacturers currently use 3D metrology based on optical or laser systems to validate products quality. The pieces are initially measured by 3D scanning then they are compared with the designed model (CAD file) using a specialized software. The overall accuracy of a 3D acquisition system depends above all on the sensor's precision and on the acquisition device (acquisition with contact) or acquisition structure (acquisition without contact). This accuracy may vary from micron to millimetre and the acquisition's size from a few points to several thousand points per second. In a perfect world or in an integrated production environment, 3D measuring systems should be able to measure all the necessary parameters in a single step without errors, and to render the results in the same way to the manufacturing networks equipped with computers, in formats useful for machines control and processes management.*

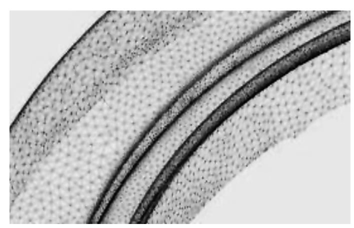
Keywords: *3D scanning****,*** *modelling, dimensional control*

1. INTRODUCTION

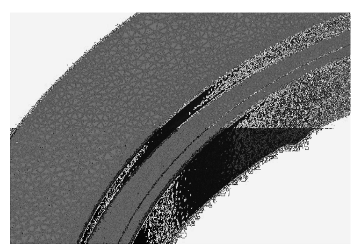
Three-dimensional measuring (3D) is a relatively new technique, continuously developing, with devices and equipment (3D scanners) still in the testing phase, but that could revolutionize and facilitate conventional measurement techniques. 3D scanning is the process of copying digital information of physical object geometry (solid), therefore it is known as digitization [1]. "*Digitization*" or "*3D digitization*" is a process that uses a digitizing probe with contact or non-contact to capture the form of objects and recreate them in a virtual workspace through a very dense network of points (xyz) in the form of 3D graphical representation. The data are collected in the form of points and the resulting file is called "cloud of points" (Figure 1a) after which they are usually post-processed in a network of small polygons that are called 3D polygonal network or mesh (Figure 1b). This type of information can be saved in various CAD formats (Fig. 1c), the most common being the STL format (Surface Tessellation Language). A simplified definition states that the *acquisition* is done through a "*material*" interface (3D scanner) with the help of probes and sensors, and modelling through a "*software*" interface using algorithms, three-dimensional data collected being useful for a wide range of applications, three dimensional data collected being useful for a wide range of applications. Technologies used to build 3D scanning devices are many, each with its own technology limitations, costs, advantages and disadvantages.



a. 3D point cloud



b. Polygons network 3D mesh



c. Resulting surface

Figure 1.
Phase of digitization or 3D digitization [2]

2. 3D SCANNING TECHNOLOGIES

Even if intended for copying or geometrical control, or rather virtual geometric modelling or product realization, there are two groups of technologies: 3D scanning with or without contact (Figure 2). Until recently, digitization was limited by the speed of the scan head and the correct choice of the probing system, type of scanned piece and budget for the purchase or developed the scanning system. Non-contact 3D scanning can be further divided into two main categories, active scanning and passive scanning. The term "contact" refers to the control palpation or recouping by mechanical contact of surfaces (probe surface - piece surface) while non-contact technologies (without mechanical contact) use optical or laser light sources for faithful reproduction of the scanned surface. Before obtain optimum results with any technology, it is vital to ensure that acquisition technology (sensory) corresponds to the selected application and the criteria of accuracy, resolution, acquisition speed, speed measurement or configuration degrees of freedom right and repeatability are taken into account.

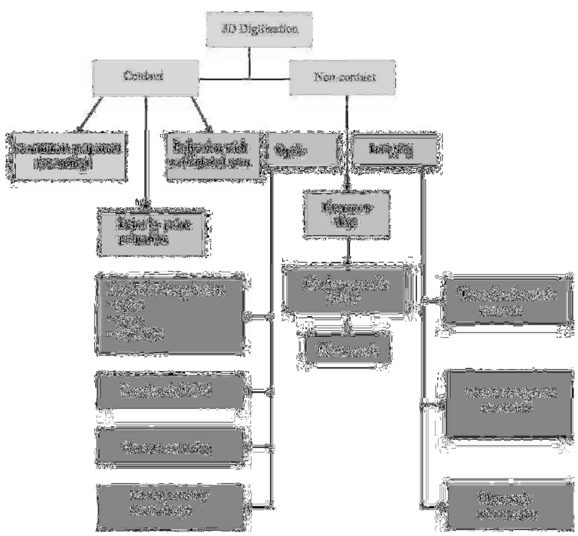


Figure. 2. 3D digitizing technology

2.1. Contact 3D scanning technology

In the 3D measure probe touch measurement test subject, while the object is in contact with or resting on a precision flat surface plate. Where the object to be scanned is not flat or cannot rest stably on a flat surface, it is supported and held firmly in place by a fixing device. The scanner mechanism may have three different forms:

- a carriage system with rigid arms held tightly in perpendicular relationship and each axis gliding along a track. Such systems work best with flat profile shapes or simple convex curved surfaces.
- an articulated arm with rigid bones and high precision angular sensors. The location of the end of the arm involves complex math calculating the wrist rotation angle and hinge angle of each joint. This is ideal for probing into crevasses and interior spaces with a small mouth opening.
- a combination of both methods

2.2. Non-contact 3D scanning technology

While 3D contact scanning techniques using probes for a scan non-contact technologies use optical sensors, laser light sources, or a combination of both (this are the most economically and technologically viable). Other non-contact scanning methods are photogrammetry, X-rays, CT and MRI scan. Non-contact laser sensors and the visual one were developed as an alternative to replace those with contact, where physical contact is not possible in case of fine or gently finished surfaces, super-finished or high ruggedness and those with sharp edges.

2.3. 3D video-laser scanning technology

In modern engineering, the term "laser scanning" is used with two related, but separate meanings. The first, more general, meaning is the controlled deflection of laser beams, visible or invisible.[3] Scanned laser beams are used in stereolithography machines, in rapid prototyping, in machines for material processing, in laser engraving machines, in ophthalmological laser systems for the treatment of presbyopia, in confocal microscopy, in laser printers, in laser shows, in Laser TV, in LIDAR, and in barcode scanners. The second, more specific, meaning is the controlled steering of laser beams followed by a distance measurement at every pointing direction. This method, often called 3D object scanning or 3D laser scanning, is used to rapidly capture shapes of objects, buildings and landscapes. Materials that can be scanned using video laser scanning technology are: stone, ceramics, glass, metal, wood, plastic, rubber, clay and organic material. One of the main advantages of the laser beam is that it can penetrate even the smallest cracks of the scanned surface (Table 1). The pieces are initially measured by 3D laser scanning and then they are compared with the model designed (CAD file) using specialized software.

The main methods for creating 3D models (mesh) are:

- polygonal modeling - most models used in games and movies are polygonal models.
- parametrical modeling - the parameters are used to specify properties of the object;
- 3D solid modeling - in this method are used elementary geometrical objects such as cubes, cylinders, cones and spheres, to build more complex models;
- NURBS modeling (Non-uniform rational B-spline) - unlike polygonal modeling, offering the ability to create smooth curved surfaces, but the rendering is slower;
- molding based on Spline curves or on Patch tipe surface - is the same as NURBS model, with the exception that the faces are made of curved lines, that is their edges.

Resolution of a mesh is actually the density of the number of points or the distance between points. Distance between points is usually of the order of 0.01 mm - 0.1 mm. This value should not be confused with precision measurement system because many of 3D scanning equipment manufacturers are hiding under the umbrella of this information when are asked about measurement accuracy.

Table 1. Analysis of technical solutions of different probes

Type of technology	Advantages	Disadvantages
Mechanical probe point by point	Very accurate (1/100mm) Low price Independent of color and texture Small dimensions	Very slow (1 point to 4 seconds) Contact pressure Limited workload It is not suitable for the reconstruction of complex shapes
Analog mechanical probe	Accurate Economical Independent of color and texture Small dimensions Flexible and optimal for rebuilding the forms of mechanical parts	Relatively slow (averaging 100 points/ sec) Contact pressure Limited workload
Laser point	No contact Relatively fast (averaging 200...300 points/ sec) Variable working distance	Depends on the appearance of surface Relatively expensive Is not suitable for very rough shape Variable precision Relatively difficult to use
Laser plane	No contact Very Fast (> 10000 points / sec) Variable working distance	Depends on the appearance of surface Expensive Variable precision (1/10 mm) Relatively difficult to use Noise and parasites
Optical	No contact Very fast (420,000 points / sec) Variable working distance Measurement of moving objects Large dimension	Depends on the appearance of surface Expensive Variable precision Complex further processing Complex usage

3. MAIN TYPES OF 3D VIDEO-LASER SCANNERS

The time-of-flight 3D laser scanner is an active scanner that uses laser light to probe the subject. At the heart of this type of scanner is a time-of-flight laser rangefinder which measures the "time travel" of the emitter laser scanned surface.. The laser rangefinder finds the distance of a surface by timing the round-trip time of a pulse of light. Since the speed of light „*c*“ is known, the round-trip time determines the travel distance of the light, which is twice the distance between the scanner and the surface. If „*t*“ is the round-trip time, then distance is equal to $c^{*}t/2$. The accuracy of a time-of-flight 3D laser scanner depends on how precisely we can measure the time „*t*“: (approx. 3.3 picoseconds is the time taken for light to travel 1 millimeter).
The laser rangefinder only detects the distance of one point in its direction of view. Thus, the scanner scans its entire field of view one point at a time by changing the range finder's direction of view to scan different points. The view direction of the laser rangefinder can be changed either by rotating the range finder itself, or by using a system of rotating mirrors, typical time-of-flight 3D laser scanners can measure the distance of 10,000~100,000 points every second. The disadvantage of this type of laser scanner precision due to high speed of light, timing the round-trip time is difficult and distance measurement accuracy is relatively low, of the order of a few millimeters.

The triangulation 3D laser scanners are also active scanner that use laser light to probe the environment. 3D laser scanner whit triangulation use a laser on the subject and exploits a camera to look for the location of the laser dot (Figure 3). Depending on how far away the laser strikes a surface, the laser dot appears at different places in the camera's field of view which is related to a coordinate system. This technique is called triangulation because the laser dot, the camera and the laser emitter form a triangle. The length of one side of the triangle, the distance between the camera and the laser emitter is known and the angle of the laser emitter corner is also known. The angle of the camera corner can be determined by looking at the location of the laser dot in the camera's field of view. These three pieces of information fully determine the shape and size of the triangle and gives the location of the laser dot corner of the triangle. In most cases a laser stripe, instead of a single laser dot, is swept across the object to speed up the acquisition process. They have a limited range of some meters, but their accuracy is relatively high compared to 3D time-of-flight type scanners. The accuracy of 3D triangulation scanners related to is on the order of tens of micrometers.

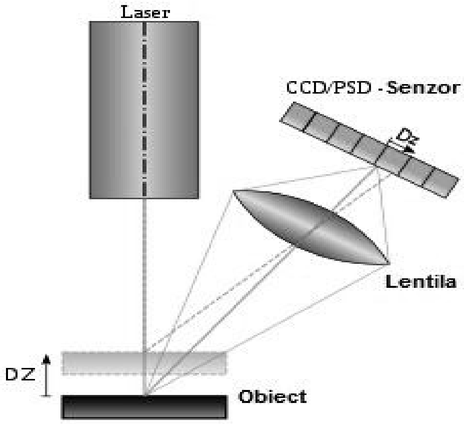


Figure 3. Principle of triangulation 3D laser scanner

3D Conoscopic holography scanners. In a conoscopic system, a laser beam is projected onto the surface and then the immediate reflection along the same ray-path are put through a conoscopic crystal and projected onto a CCD. The result is a diffraction pattern, that can be frequency analyzed to determine the distance to the measured surface.

The main advantage with conoscopic holography is that only a single ray-path is needed for measuring, thus giving an opportunity to measure for instance the depth of a finely drilled hole.

3D Structured light scanners project a pattern of light on the subject and look at the deformation of the pattern on the subject. The pattern is projected onto the subject using either an LCD projector or other stable light source. A camera, offset slightly from the pattern projector, looks at the shape of the pattern and calculates the distance of every point in the field of view. Instead of scanning one point at a time, structured light scanners scan multiple points or the entire field of view at once which gives an advantage.

Modulated light 3D scanners shine a continually changing light at the subject. Usually the light source simply cycles its amplitude in a sinusoidal pattern. A camera detects the reflected light and the amount the pattern is shifted by determines the distance the light traveled. Modulated light also allows the scanner to ignore light from sources other than a laser, so there is no interference.

4. INDUSTRIAL APPLICATIONS

In present, 5 great family of applications stand in procedures of scanning-digitization:

- *reverse-engineering* intended for reducing the time of conception for CAD systems when using models; in this case, processing the obtained points cloud must be integrated into a phase of reconstruction of surfaces through some special software [4];
- *metrology-control-quality* for accurate measurement of uniform parts with complex shapes with very variable dimension: controls on the production line in order to select or statistical mastery a process, for correlating certain parameters of the manufacturing chain (Figure 4);
- *biomedical*, to adapt the prosthesis prior interventions or within aesthetic treatments, but also for characterizing the volume of organs based on ultrasonography, scan, etc.
- *digitization*, before or after the rapid prototyping of copying systems by processing on the numerical control machine tools;
- *motion picture and video animation* (virtual images).

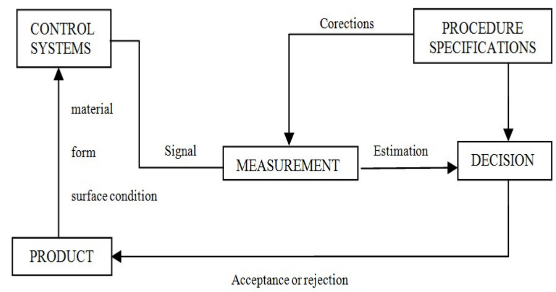


Figure 4. Metrology-control-quality: interactions.

Importance and accuracy of 3D scanning is dictated by the application tracked, so applications in the medical field, which usually does not require a very high tolerance (± 0.3mm) or in the cultural-historical field (archaeology), can use a wide range of 3D imaging techniques (contact or noncontact) to achieve desired results. But in the auto industry, we can use only certain types of 3D scanning, because it is needed rather high limit of data quality, tolerances acceptable in most cases being between ±0.001mm....±0.01mm [5]. 3D scanning techniques and the rapid prototyping plays an important role in the techniques of R.E. in the automotive industry, even if a procedure of R.E. does not necessarily mean physical realization of the prototype.

Concrete applications of the present scientific work will be done by the design and physical realization of equipment mechatronic adaptronic intelligent to the family of complex automotive parts (crankshaft, flywheel, rods, etc.).

5. THE IMPACT OF 3D SCANNING TECHNOLOGY ON PRODUCT DEVELOPMENT

Companies adopt new techniques and try new ways for efficiency of production and costs in order to meet the requirements of the current global production. Among recent technological breakthroughs, there is great interest in laser scanning, which is fast and available. Often, the time required to sell products decide the development of the new product why that the companies try to work with their clients more in the design better understanding their needs before production stage [6]. Scanning and post editing process can be done in only 4-5 hours thus result a time saving that can be used by companies to respond quickly to market changes. Another advantage for manufacturers is that in many cases the G code for CNC equipment can be created directly from the scanned data or by CAD file without including production stage of a model with surfaces. This means that a prototype can be made and approved, scanned, followed by the realization of a mould that can be made quickly and easily, all in one day. The scanned data can be translated to any file formats: DXF, OBJ, 3D Studio Max, IGES, STL ASCII and accessible to a large number of devices. Product verification is another example of the scanning benefits. Once a product has been produced, it can be scanned and the resulting data compared with CAD geometric models and deviations from the original geometric model can be determined precisely.

Another advantage that is not so obvious, but can have a big effect on a company, is that once the object is in the computer, complex ideas can be applied easily and accurately. Thus, manufacturing processes are carried out in several subsidiaries of a company in different locations around the globe. Once a prototype has been scanned, engineering, analysis, quality control and other functions which usually took place in succession can take place in the same time before sending the product to manufacture.

6. CONCLUSIONS

In a perfect world or in an integrated production environment, 3D measuring systems should be able to measure all the necessary parameters in a single step without errors, and to render the results in the same way to the manufacturing networks equipped with computers, in formats useful for machines control and processes management.

3D laser scanning offers a lot of advantages, like: quick and easy to use, the results can be compared with the initial one, is accurate and non-destructive, very useful for areas that cannot be measured by classical methods (with contact) and adaptive (can be used in combination with other methods of scanning).

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