Computer-Aided Process Planning for automatic generation of 3D digitizing process for laser sensors

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ABSTRACT

This paper introduces some results of a research work carried out on the automation of digitization process of complex parts using a precision 3D-laser sensor.

It will be presented a new way to scan automatically a complex 3-D part in order to measure and to compare the acquired data with the reference CAD model. Due to the fact that rapid prototyping processes do not allow the direct manufacturing of high precision parts, it is very often necessary to measure a first part in order to modify the process parameters.

After introducing the digitization means, based on a CMM machine and a plane laser sensor, the simulation environment will be presented as adapted for simulation and validation of 3D-laser scanning paths. The CAPP (Computer Aided Process Planning) system used for the automatic generation of the laser scanning process will also be introduced.

Keywords: scanning process simulation, inspection, optimization

1 INTRODUCTION

Life cycle of new products needs time compression, from early design stages to industrial production. Rapid prototyping (Bernard & al., 1998) is very often used to produce test parts representative of CAD model. The objective of digitalization consists, starting from a physical object, in acquiring a digital image of the surfaces of the parts on a point cloud form. After a processing to make it coherent, this cloud is exploitable by CAD software for the surface reconstruction of the part, its manufacture or its measurement (Figure 1).

In this project, and due to industrial demands, the main objective is measurement of prototype parts or tools, in order to verify their conformity to the reference CAD model. In this field of application, the efficiency of the first step of the process "scanning – point cloud treatment – surface (or volume) modeling or technological applications (STL, CNC, ...)" (Figure 2) is one of the main important steps of control process because it decides of how the part will be digitize, and mainly of the final result.

The challenge of the presented project is to automatically generate the measuring process of the part in order to be able to characterize the errors compared to the CAD reference model.

This complete goal contains different sub-objectives. The first one is to be able to simulate and to validate a scanning process for a plane laser sensor, and, at last, to automatically generate this scanning process and the corresponding sensor paths. The context is defined as follow:

- the digitalization environment (CMM, sensor) is known and the chinematics parameters are defined,
- the CAD model of the part to be measured is the reference and is numerically defined.

The fact that the CAD model of the part is known involves that this is not reverse engineering objective (Bernard & al., 1998) (Zhang & al., 1995) but the goal is the inspection (or measurement) result and the comparison of point clouds with the CAD model (figure 3).

The main problem is to obtain rapidly digital data from scanning process in order to have an efficient comparison between the reference CAD model and data obtained by digitization (Moron, 1996)(Prieto & al., 1998).

The main application fields of this application are rapid product development, and more especially foundry and plastic injection applications. So, geometry of parts is very complicated and mechanical probes are not well adapted for data acquisition. In order to reduce time consuming and to improve point cloud density, it has been decided to use a plane laser sensor. One of the major improvements of the complete inspection process using laser sensor is to automate off-line generation, simulation and validation of the laser sensor scanning process.

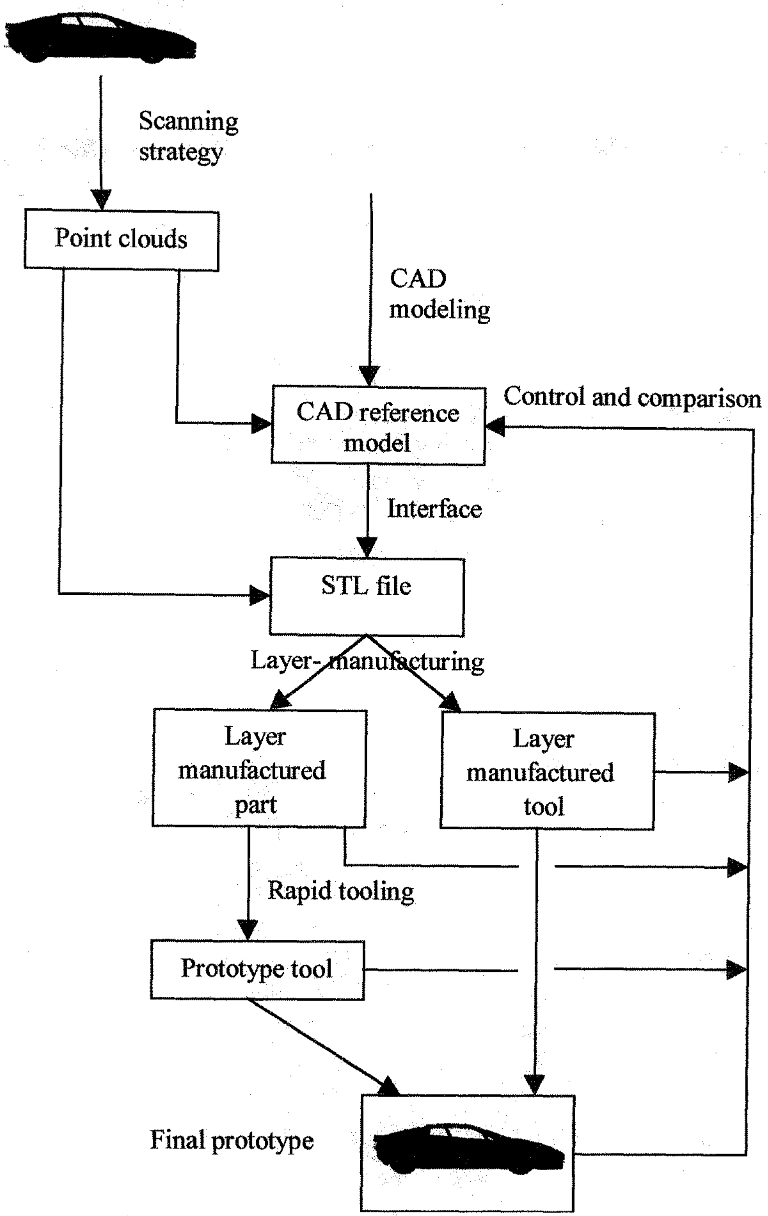


Figure 1. Rapid prototyping process

In order to proceed this project, it was decided to invest in a 3D precision system (laser sensor integrated on a CMM). Then we initiated an analysis of the digitizing process, using such means, with the intention of automating maximum operations of global acquisition process (Varady & al., 1997).

In this paper, it will be presented a brief description of the environment on which was based this research, and more particularly of the integration of the laser sensor. After a brief analysis of the steps of scanning, the proposed simulation and validation of 3D-laser sensor scanning process will be presented. Finally, some elements for the automatic generation of the scanning process (determination of the related positions between part and sensor, trajectory definition) will also be introduced and argumented.

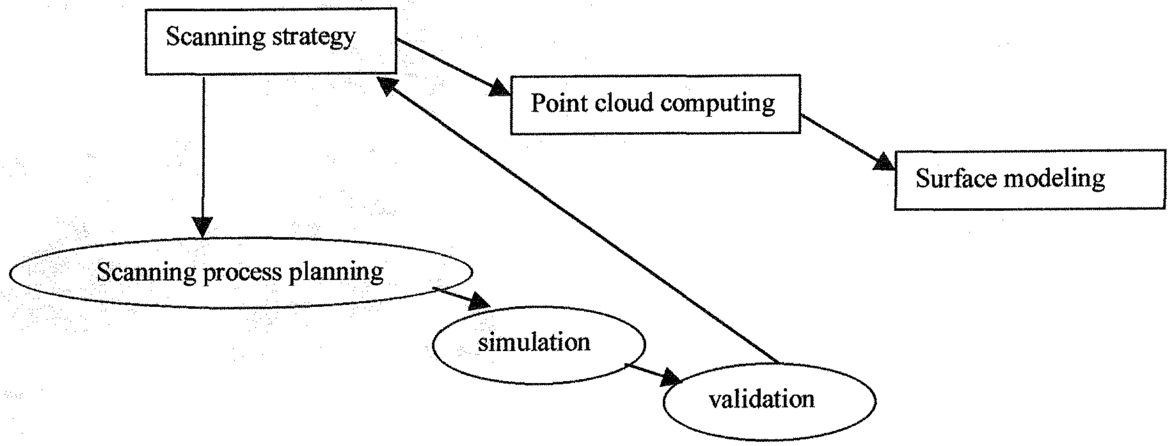


Figure 2. Scanning and modeling process

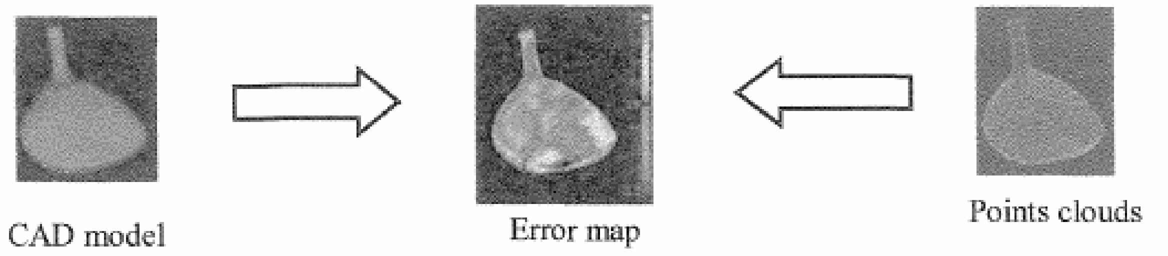


Figure 3. Control objective and environment

2 SCANNING WORKCELL

Laser sensors are materially unable to completely digitize a complex part in only one relative orientation between sensor and part. According to part complexity and according to sensor technical specifications, it remains areas where digitalization is not possible. These areas are the result of shadow or occultation phenomena depending whether the surface part is seen by the camera but non-enlightened, or the surface indeed enlightened but unseen by the camera.

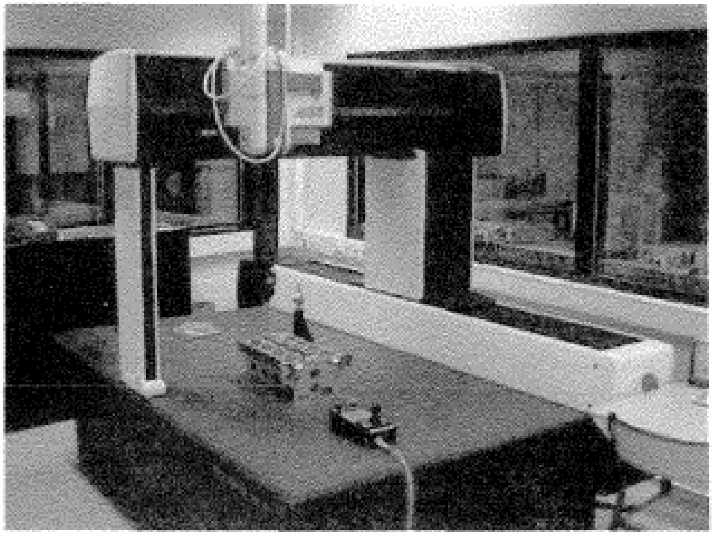


Figure 4. Coordinate measuring machine

The digitization cell is made with a coordinate measuring machine (CMM) GAMMA 1203, from DEA (figure 4) and a laser sensor from Kréon Industrie (Kréon Industrie, 1997). It is made of the 3D plane laser sensor KLS 51 (Figure 5), an Electronic Control Unit (ECU) and the “Kréon Reporter Plus” software. This environment has been detailed in (Davillerd, 1998).

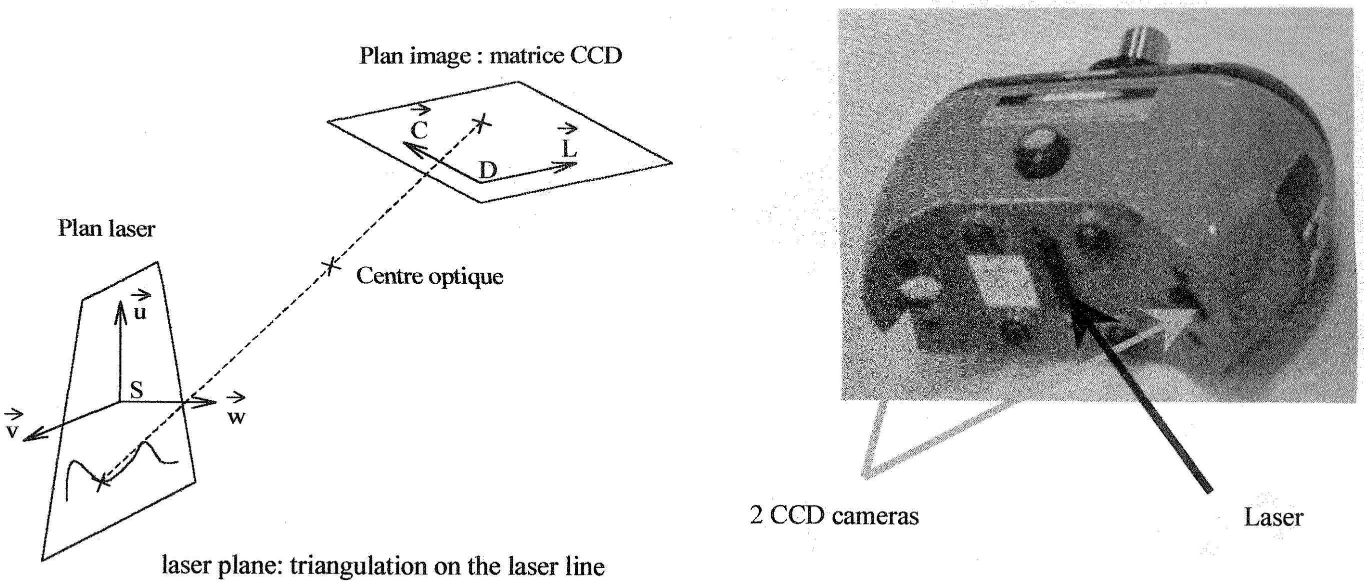


Figure 5. KLS 51 laser plane sensor

Furthermore, it can be noticed that thanks to the software and to the mechanical interface between the CMM and the sensor, the Kréon acquisition system is able to manage 4 positions of sensor, around the Z-axis, imperatively parallel with machine axes.

Based on the active triangulation principle, the sensor uses plane laser technology and is equipped with two CCD (Charge Coupled Device) cameras, placed here and there of the laser plane. The use of two cameras instead of only one allows attenuating the problems involved in the shadow or occultation phenomena on complex parts and increasing the number of points acquired with each digitization.

The Kréon acquisition system has a measurement field of trapezoidal form with a 45-mm depth. This characteristic confers on the user facilities for the creation of trajectories by reducing the movements necessary to place the surface to be scanned in the measurement field.

3 DIGITIZATION IMPROVEMENTS

In this environment, a complete analysis of the digitalization process has been proceeded to find the critical stages, which will be studied and improved. A flow shart describing this process is detailed in (Davillerd, 1998). It has been decomposed into three main steps: scanning process definition, scanning process execution, and data acquisition computing. In the following, each of these three steps will be detailed.

3.1. Scanning process definition.

This step consists in several stages like: digitization strategy definition, machine calibration, sensor calibration, software origin definition, part set-up, and strategy implementation. Only two of them are very critical: digitization strategy definition and strategy implementation.

Digitization strategy definition is the stage in which the user defines part orientations and sensor orientations that needed to digitize the part. Also, he has to define reference features to be able to readjust point clouds in a next stage. These reference features can consist in part features or in features added on the part or in a rotation axis.

Strategy implementation is very time consuming. Indeed, the user has here to define sensor trajectories. So he programs the coordinates of linear movements and indicates to the system the moment along with it has to digitize (Figure 7). He also chooses the acquisition step. In this way, he also implicitly defines the recovery (number of point that will be digitized in more than one position, and that will have to be filtered).

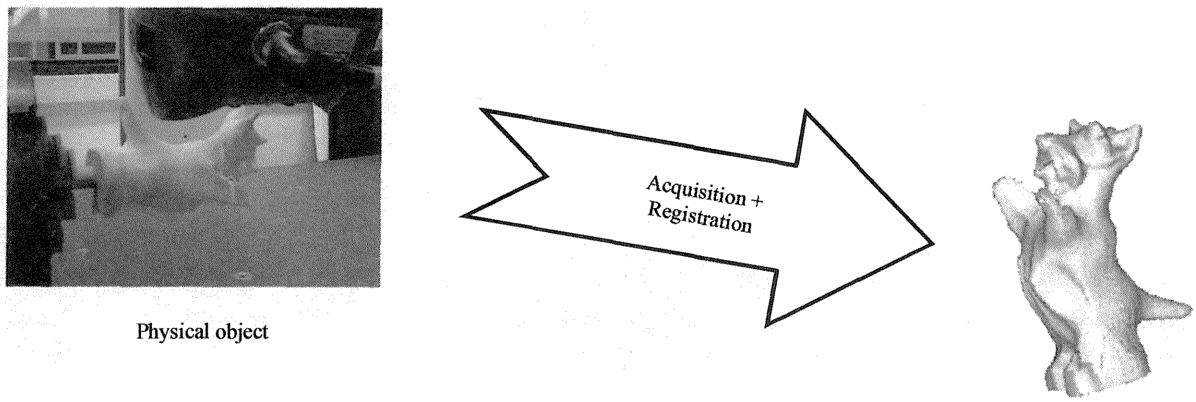
3.2. Acquisition execution.

Starting from the trajectory file defined by the user, the ECU pilots the sensor in the machine reference system and Kréon Reporter Plus software records the acquired points. Everything is automatic and has not to be improved.

3.3. Data acquisition computing.

It consists in two steps. First, point cloud filtering is necessary because the acquisition generates an important quantity of points. Consequently a simplification is necessary and consists in grid application. But the needed quantity and quality of points essentially depends on the using application: for example point machining, surface reconstruction or imaging.

And finally, the readjusting stage is very important because it conditions the final results. Each point cloud is defined in a particular frame then all frames have to be regrouped in a unique one. This operation can be made manually or by using matrices. Then, after the part is digitized according to the defined strategy, the whole numerical information of the part is defined (figure 6).



Physical object

Numerical model

Figure 6. The part on its fixture and the final point cloud.

4 SIMULATION AND VALIDATION

Scanning is a "step by step" process. This means that the CMM moves, then stops its movements, the sensor acquires data and the CMM moves again. Thus, each acquisition is a discrete event. Let us detail this event for the 3D-laser-scanning sensor KLS 51.

The first stage is the part illumination by the laser. A plane laser lights the part up. A beam coming from a laser diode creates this plane. This beam goes through a cylindrical lens in order to create the plane. This plane is about 0.3 mm thick in the middle of the measurement field.

The second stage is the scene acquisition. Each camera takes a gray level image of the scene. Each CCD camera acquires the laser trace on the part and its thickness.

The third and last stage is the image computing. Each image is processed in order to generate 3D coordinates of acquired points. First, image is cut in order to keep interesting information. This treatment defines the trapezoidal sensor measurement field. A numerical treatment called sub-pixel algorithm is then used to reduce thickness to one point. Triangulation calculation allows the system to extract the three dimensional coordinates of 300 points on the trace length (Kréon Industrie, 1997).

The objective of simulation is to visualize CMM movements and each acquisition of the sensor. So, it has been necessary to model the digitization cell in a robotic CAD environment (CIMSTATION INSPECTION from Silma). Several applications exist (Chedmail & al., 1998): spot welding, arc welding, painting and projection are available. Collision between the sensor and the digitization environment can be detected as well.

The analysis of this environment shows that sensor actions could be similar to paint deposition. (Silma, 1998). Indeed, laser beam action is the illumination of part surface and it could be compared with a paint deposition on the lighting area. In the same way, camera action is the part surface observation and it could be compared with a paint deposition on the viewed area. In this way, the plane laser sensor work has to be adapted in the chosen robotic CAD software from the paint deposition simulation.

So, a solid model of the laser sensor has been adapted on the head of the machine in CIMSTATION ROBOTICS environment. Attachment, 4-positions interface and sensor surface models are reconstructed from IGES CAD files with CIMSTATION functions (Figure 7).

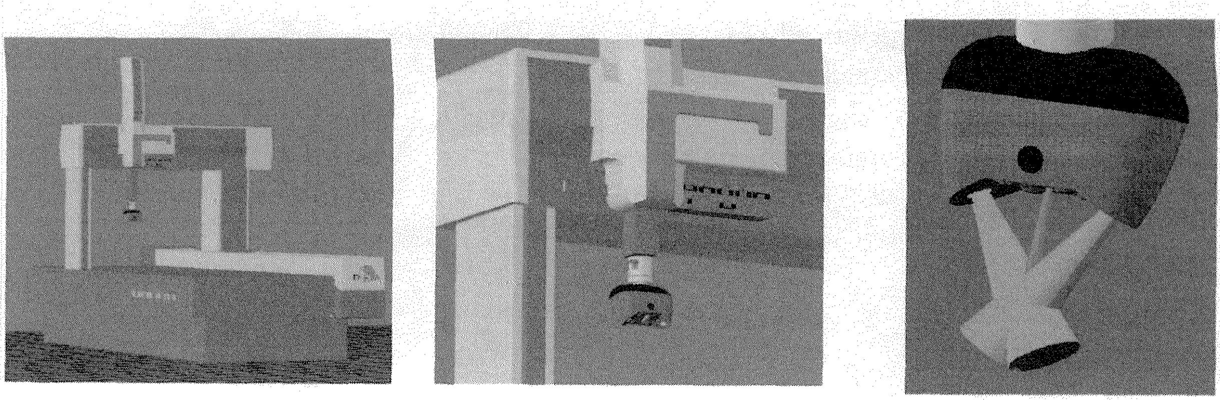


Figure 7. Models of machine, sensor and simulation features.

Original models have been proposed for the laser and each camera, adapted from paint plumes, which have special paint deposition function. Laser plume model has been created from a cone plume. The measurement field restriction treatment has been integrated in this plume; i.e. laser plume paint deposition will only be effective in the measurement field area. Each camera plume model has been created from a cone plume too. Then the intersection of the area painted by the laser plume and the area painted by either camera plume corresponds to the digitized points. Sub-pixel algorithm allows a compromise between laser width, mesh size of the CAD model and a realistic time to execute calculations in order to keep an interactive exploitation of the results.

In conclusion, digitization cell and sensor have been modeled (Davillerd, 1999). It is now possible for each particular 3D part to simulate digitization trajectories that should have been previously created. Based on these elements, off-line simulation allows testing and verifying digitization trajectories efficiency without immobilizing the digitization cell. More over, it is also possible to validate these trajectories by the analysis of the valid points (enlightened and seen by one or two cameras) obtained using the simulation module. The analysis algorithm is under validation.

5 COMPUTER-AIDED PROCESS PLANNING FOR AUTOMATIC GENERATION OF 3D DIGITIZING PROCESS FOR LASER SENSORS

In this paragraph, an analysis is proposed in order to generate an automatic scanning process.

As mentioned earlier, the objective is control. In this field, two configurations are possible. At first, the CAD model of the part is known and it has never been scanned. It is almost necessary to generate all the process to digitize the part. The second hypothesis is that the part has already been scanned manually and the result is not satisfactory (empty areas or too much redundant points). In these cases, the proposed algorithm has to define a new efficient scanning process.

In fact, we think that two stages are necessary to generate an automatic scanning process. The first stage is the determination of the different orientations between the sensor and the part, and the second stage is the definition of the trajectories, for each orientation, which allow digitizing the maximum part surface. In the following, we suggest different concepts to solve these two stages.

5.1 Definition of the relative orientations between the sensor and the part.

For the first stage, we need to know whether the surface element S_i is located in the laser measurement plan and whether one of the two cameras sees the entire or a part of the ray projected by the laser on the surface element S_i. These conditions refer to a visibility concept. It has been studied in different application fields, like machining (Risacher, 1997)(Chen, & al., 1992), inspection with mechanical probe (Spyridi & al., 1989) and inspection with computer vision (Trucco & al., 1997). Into machining and inspection with a mechanical probe field, the resolution of the visibility is based on spherical geometry. Chen (1992) introduced it for machining and Spyridi (1994) for control. This technique studies the visibility (V_i) of each part surface and the machine visibility (V_f). Both of them are described by a point, a line or a surface onto the Gaussian sphere (Chen, 1992) (figure 8). The orientations of the part and of the tool are computed by intersecting the maximum of part surfaces visibility with the machine visibility. If any surface visibilitys are intersecting with the machine visibility, then all the surfaces can be machined or inspected with only one part and sensor orientation (figure 9).

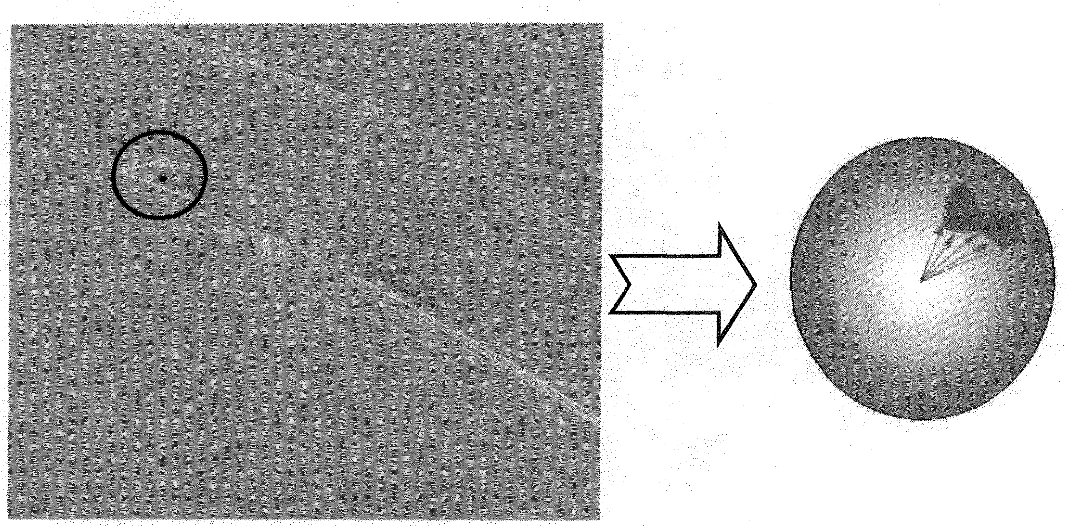
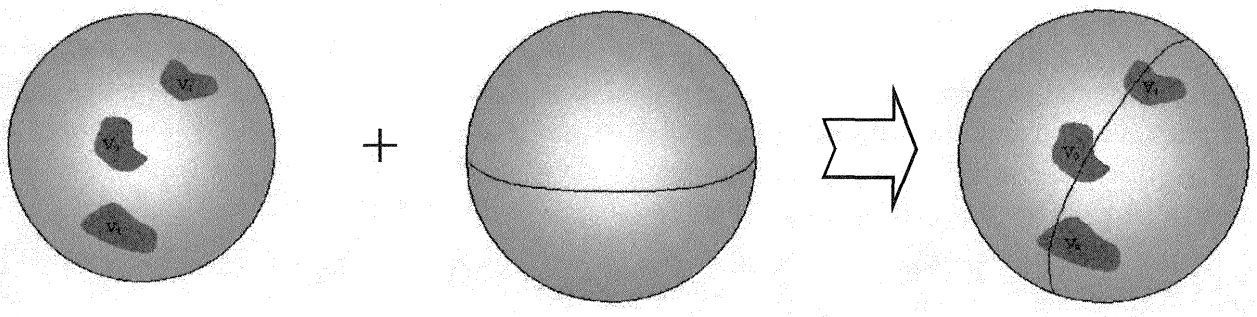


Figure 8. Part STL elements and visibility characteristics.



Every surfaces visibility

Visibility of the machine

One possible solution

Figure 9. Intersection of part visibility and machine visibility.

5.2 Trajectories definition.

When the part and the sensor have been oriented, the trajectories can be defined. According to the automatic determination of these trajectories, some examples can be found in machining field (Risacher, 1997) and in robotic field. In the first field, Dragomatz (1997) made "a classified bibliography of literature on NC milling path generation". This paper is useful to seek an introduction to the literature as a whole. It is partitioned into categories and papers to path generation classified according to the topics they cover. In the same way, Chedmail (1998) describes the different methods of path planning in robotics. The goal will be, after adaptation and transformation of these methods, to optimize the trajectories for each related position between the part and the sensor.

5.3 Constraints for the automatic scanning process generation.

Different solutions have been introduced to generate an automatic scanning process. But, there are several constraints that must be taken into account during the algorithm development.

One of these constraints is the recovery, which is not mastered by the user when he defines the process. When the system defines a trajectory, it takes account to the recovery otherwise there may be redundancy or missing of points. This recovery notion (figure 10) is difficult to master because of the laser measurement zone form. The trapezoidal form makes that when the part surface is located at the top end of the measurement zone, the trace projected by the laser is smallest than when the part surface is located at the bottom of the zone.

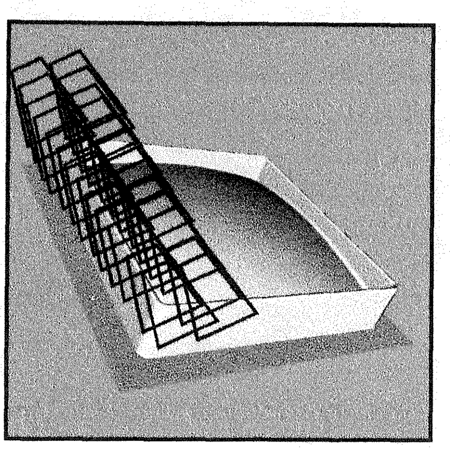


Figure 10. Path recovery.

Concerning the measurement zone, the acquisition is possible in the all weight of the zone, i.e., the sensor can move in the same z-coordinate; the part surface can vary in z, and stay in the measurement zone. The difficulty in this case is to model the "tool". For example, in machining, the tool works with its end. It is also true with a touch probe. It is more complicated to specify the active part of the laser plane.

Another constraint is the angle between the laser beam and the part surface. Even if the algorithm determines a visibility, it must be verified that the angle does not keep away from the normal of the surface.

6 CONCLUSION AND OUTLINES

Control of complex part needs to be improved in term of scanning efficiency. This contribution is related to "simulation – validation – CAPP for generation of 3D-laser scanning process".

At this time, the first step has been implemented and the second one is under development. The third one will be achieved in October 1999, based on spherical geometry.

The final complete system will contribute to optimize the development of new products and to accelerate the control phase.

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