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AUTOMATION OF THE THREE-DIMENSIONAL SCANNING PROCESS BASED ON DATA OBTAINED FROM PHOTOGRAMMETRIC MEASUREMENT

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ABSTRACT

The article presents a general concept of the automation of a three-dimensional scanning process using structured light projection technology. To take measurements, a scanner is moved and positioned in set points by a robot. A cloud of points, representing the scanned object and generated as a result of the photogrammetric measurement process, is used as input data for the creation of the robot control program. A model generated in the process is analyzed by an application which has been developed by the authors and which calculates positions for the industrial robot with a fitted scanner. The described procedure has been tested during measurements of car body parts using a GOM Atos scanner, a Tritop photogrammetric system and a Kuka industrial robot.

KEYWORDS

Reverse Engineering, Photogrammetry, 3D Scanning.

1. INTRODUCTION

The engineering design process is nowadays widely supported by CAD/CAM/CAE systems which have become a key tool of engineering designers. To be able to develop a technical product, one must create its digital images, for use in the computer design records but also virtual simulations, engineering calculations, optimization of design and development of technological software.

From the other point of view, the shapes of products are becoming more and more complicated as the customer's esthetical and ergonomic requirements grow. A model or utility design is often created by a visual artist or stylist designer who uses traditional materials including wood, clay or plastic foam. Consequently, the complex surfaces created in result of artistic ideas are very difficult to represent using conventional CAD tools.

Digital representations required in the different stages of the product development process are often obtained using reverse engineering (RE) methods. The objective of RE is to precisely recognize and document the structures, dimensions and operations of existing technical objects. This technique is often used when the documentation of a damaged or destroyed object is not available. It can also be applied for digitalization of a physical conceptual model created by a visual designer. Reverse engineering is in this case an integral part of the product development process (Sokovic and Kopac, 2006), (Zhang, 2003).

The easiest way to create a digital image of an object is to measure it using manual or automated measurement tools and, based on the obtained data, create a digital representation usually in the form of solid or surface 3D CAD models. If the shape of the object is too complicated and the usual measurement methods do not provide the number of data necessary to create a model, the 3D scanning process is used.

Techniques most frequently used for digitalization include optical scanning with the use of structured light and laser scanning (Cheng et al, 2010), (Kus, 2009), (Son et al, 2002). Both methods are very accurate, with up to 0.02 mm accuracy, but also time-consuming (despite a short time of one measurement lasting a few seconds only). In large objects scanning procedures, i.e., in case of car bodies, it is necessary to take a number of measurements from different perspectives, which lengthens the process even up to several hours.

To shorten the time needed by a scanner operator to determine at which point the next measurement should be taken, the authors propose using methods described in this study, allowing to automate the scanning process.

In the proposed methodology, coordinates of the consecutive positions of scanner, necessary to correctly collect information about the geometric shapes of the examined model, are determined on the basis of an approximate geometric model. The model is generated on the basis of quick photogrammetric measurements. There is a control program generated for the industrial robot based on the determined coordinates, which moves the scanner in the process of taking series of measurements.

There are ready-to-use systems available on the market in which the scanner is coupled with the robot. However, these systems are only used as coordination systems to determine the spatial position of the scanner based on the available CAD model, and to compare the model generated by the scanning process with the CAD model. They create a coloured map of deviations (Gom, 2010), or a set of fixed scanner positions is used to measure a class of similar objects (Callieri et al, 2004), (Zhao et al, 2008).

The solution designed by the authors, apart from determining the scanner positions for objects of known geometry, allows automating the process of scanning objects for which a CAD format representation is not available.

2. THREE-DIMENSIONAL SCANNING

3D scanning is a technique in which the shape of a real object is mapped and saved in a digital form. Optical scanners which operate based on the structured light projection method (the so-called stripe scanners) are most commonly used in reverse engineering.

The scanner's projector projects a pattern of stripes of known density on a given object. Straight lines are getting distorted adequately to the deformation of the object surface, and the image is recorded on matrixes of two cameras. Using the input data (the structure of light, the camera recorded image, the calibration parameters, and the angle between projection direction and the read-out direction) coordinates are calculated for each pixel of the camera. One measurement generates a cloud of points in a number directly depending on the resolution of the used cameras (Cheng et al, 2010).

The principle of operation of a stripe scanner is presented on Figure 1.

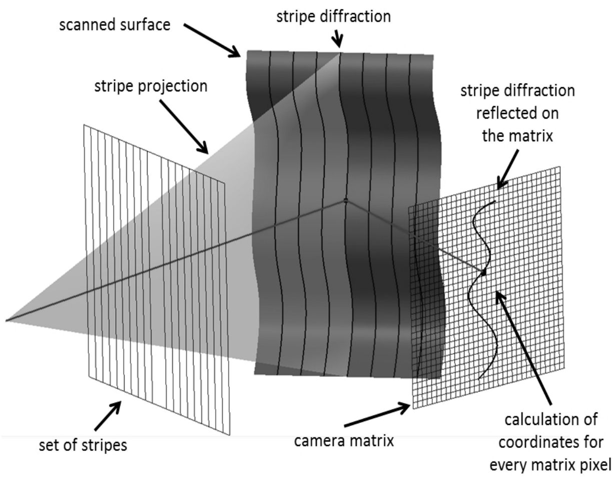

Figure 1 – Principle of operation of a 3D scanner

Engineering photogrammetry is one alternative method for obtaining three-dimensional data. It is used especially for measuring large objects or for fast inspection of object location (Clarke and Wang, 2000), (Hefele and Brenner, 2000), (Luhmann et al, 2007), (Maas, 1997).

Photogrammetric measurements in the reverse engineering processes allow generating a cloud of reference points representing a given object, on the basis of appropriately taken series of photographic pictures. Photogrammetric analysis requires suitable photographic equipment and appropriate automatic image analyzing software. Depending on the requirements, metric (phototheodolites) or non-metric cameras are used, as many photogrammetric systems allow calibrating standard digital cameras.

Specific markers are used in close range photogrammetry, some of them are positioned on the measured object (markers), others are positioned in its vicinity (code marking), allowing to orient the created pictures against each other. Additionally, scaling rods must be positioned on the photographed scene, to re-scale the produced cloud of points to their actual size.

The prepared object is then photographed from different camera positions. The received images are analyzed and, thanks to superposition of data from many pictures, three-dimensional data are generated in the form of a cloud of reference points, representing markers placed on the object. The data are then imported by the scanner software, which prevents errors connected with matching the successive "scans". If a GOM Atos scanner is used, like in the authors' study, the maximum size of the measured object should not exceed three-times the size of the measuring field (500x500mm).

By contrast, with photogrammetric measurements, objects of fifteen meters and more can be scanned without any accuracy losses. In the described project, the collected data are additionally used to create a rough model of the examined object. Based on the rough model the developed application generates the next desired space positions of the scanner for the individual areas of scanning.

3. AUTOMATED SCANNING METHODOLOGY

3.1. INITIAL PHOTOGRAMMETRIC MEASUREMENT

The algorithm of the industrial robots programming method using photogrammetric data is presented on Figure 2.

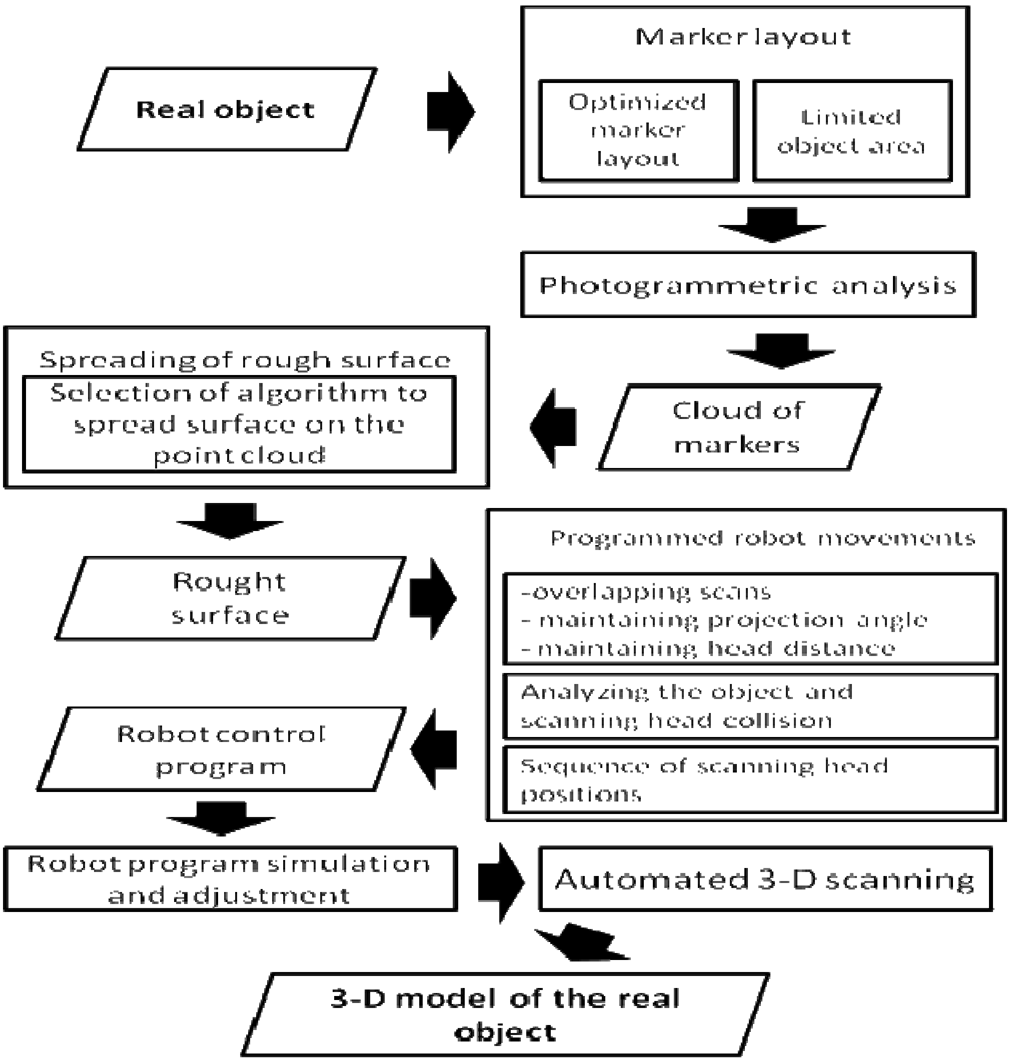

Figure 2 – Analysis of the automated scanning process

At first the object is prepared for taking photogrammetric measurements using the Tritop system. There are markers positioned on the object so that a mesh of triangles, which is spread over a cloud of points creating a rough model, corresponds as much as possible with the real object. Any characteristics points, like pockets or stacks, are also represented.

Because of the requirements of the subsequent scanning procedure, transparent and strongly reflective objects require additional tarnishing using spray chalk. The object, once prepared using the mentioned techniques, is positioned on the photographed scene together with the scaling rods and calibration crosses (Fig. 3).

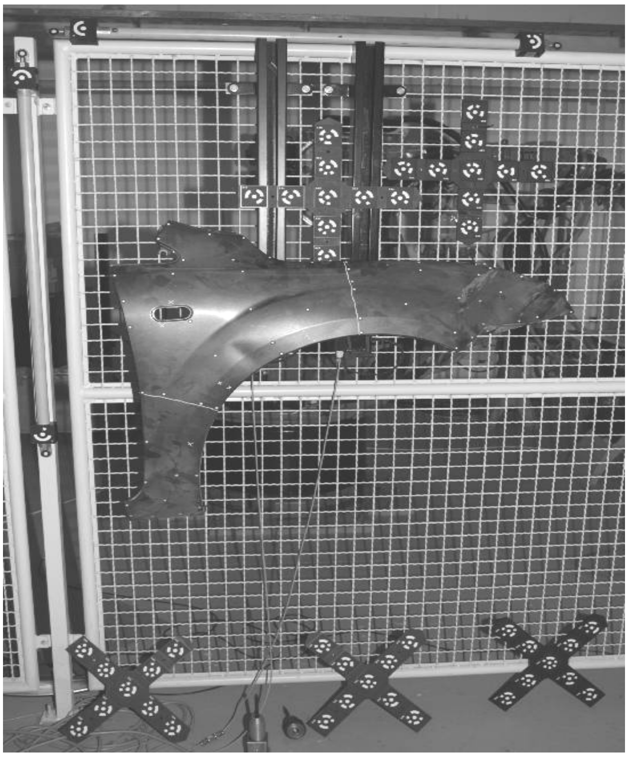

Figure 3 – Object prepared for photogrammetric measurements

Every cross has a set of code markings allowing orienting the pictures against each other. Additionally, one of them determines the origin of the local coordinate system. The next step consists in taking pictures which are sent online to a computer via a local wireless network. There they are subject to an image-based analysis, generating a cloud of reference points, reflecting markers positioned on the object (Fig. 4).

Figure 4 also presents the imaged calibration crosses, the local coordinate system and the scaling rods matched in size with the measured object.

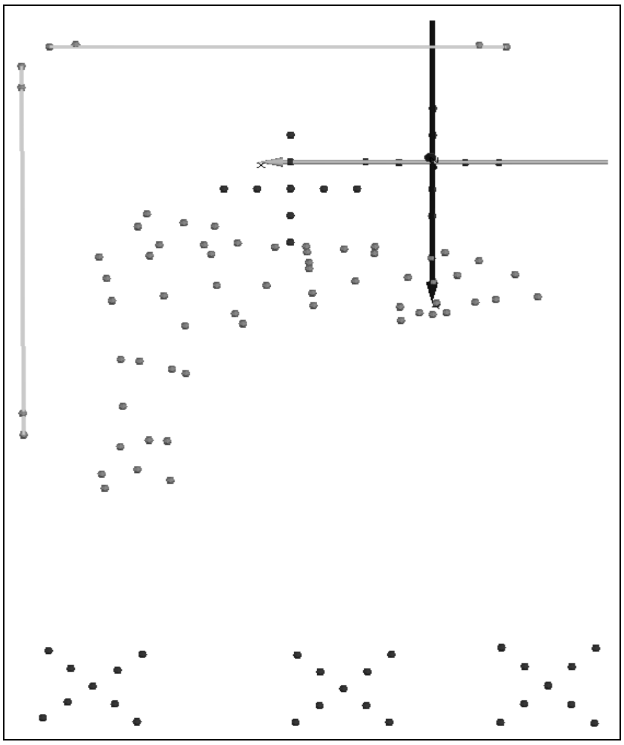

Figure 4 – Object generated using the acquired 3D data

The coordinates of points in REF format are sent to the scanner software while the same data in IGS format are imported to the Catia V5 software, where a mesh of triangles is spread and later saved in STL format. Figure 5 presents a rough model of a fender with reference points shown.

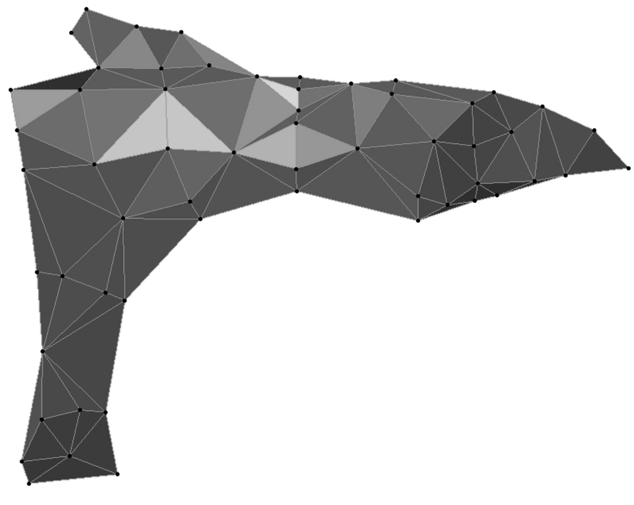

Figure 5 – Rough fender model in TIN mesh format

3.2. DATA PROCESSING FOR ROBOT CONTROL

The representation of a surface in STL format gives the coordinates of the vertexes of a mesh of triangles and the coordinates of the normal vectors of each triangle, determining the outward and inward facing surfaces. The data in text format are imported by the described application. In the first phase of the algorithm, the whole object is divided into smaller sectors of sizes directly depending on the size of the scanner measurement field.

The measurement field is a surface. However considering the scanner's depth of focus, it has been assumed that triangles included in a cube of an "a" side, defined according to the measurement field, will be searched. The location of the first cube is determined on the basis of the vertex having the smallest value of the X, Y, Z axis coordinates. The following cubes are built so that the "a" value of their sides is added, one after the other, in the positive directions of the X, Y, Z axis.

After defining the length of the cube side and its position, a filter is created in the space, which looks for all triangles present in the area of the cube from the data obtained from the STL file. A set of selected triangles also includes those which are only fragmentarily present in the set space. In the next step, the surface area of those triangles is calculated, and the weighting factor, which is proportional to the area, is determined.

Considering this factor, and based on the normal vectors of the respective triangles, an averaging direction vector is calculated for the analyzed fragments of the surface. Its origin is determined by averaging the coordinates of the centres of the triangles located in the analyzed set. An additional condition, verified in the described procedure, analyzes the values of angle deviations of every normal vector of the respective triangles, from the direction of the resultant vector.

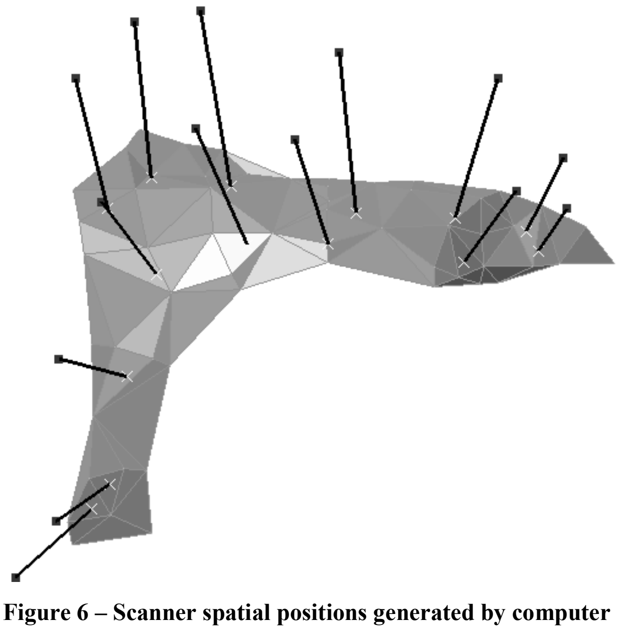

Figure 6 – Scanner spatial positions generated by computer software

Every triangle must be positioned under an angle appropriate for the averaging direction vector of the examined surface. This results from the fact that the scanner has a maximum "angle of observation" of the examined surface, allowing for correct scanning. If, for a given triangle, the deviation of angles is higher than the adopted acceptable value and, moreover, the percentage share of its surface area in the surface area of the considered fragment of solid exceeds the declared threshold value, its data, together with data of other triangle failing to meet the conditions, are saved in a separate file. The data are again loaded by the application and, determine the positions of additional scanning procedures, as soon as the analysis of other areas is finished.

For every required measurement, the position of the scanner is determined on the axis of the resultant vector, within a previously defined "l" distance, which ensures a correct scanning process. Figure 6 shows the positions of scanner, as they have been calculated by the presented algorithm for the scanned fender.

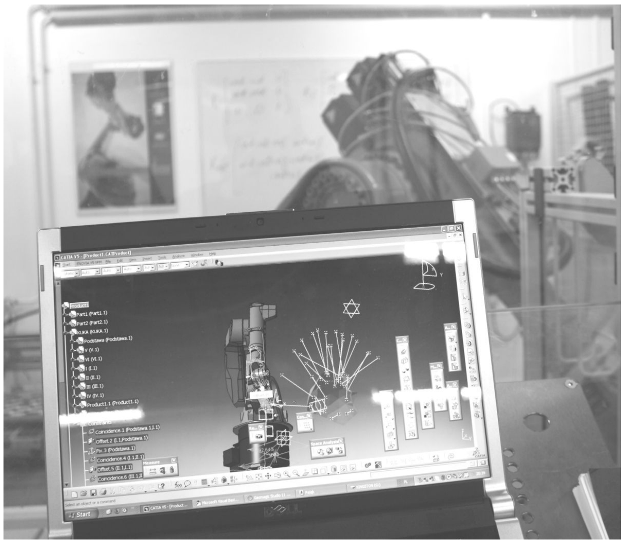

Figure 7 – Scanning simulation in Catia environment

3.3. SCANNING TESTS

The described tests have been carried out using a Kuka KR30 industrial robot equipped with a specially designed and produced GOM Atos optic scanner holder, a GOM Tritop photogrammetric measurement system and the software developed by the authors.

The Kuka KR30 industrial robot (Fig. 8) is responsible for moving the scanner to the next set position. To minimize the total scanner travel and the scanning time, there is a procedure used in the application, scheduling the points of scanning with the use of a genetic algorithm.

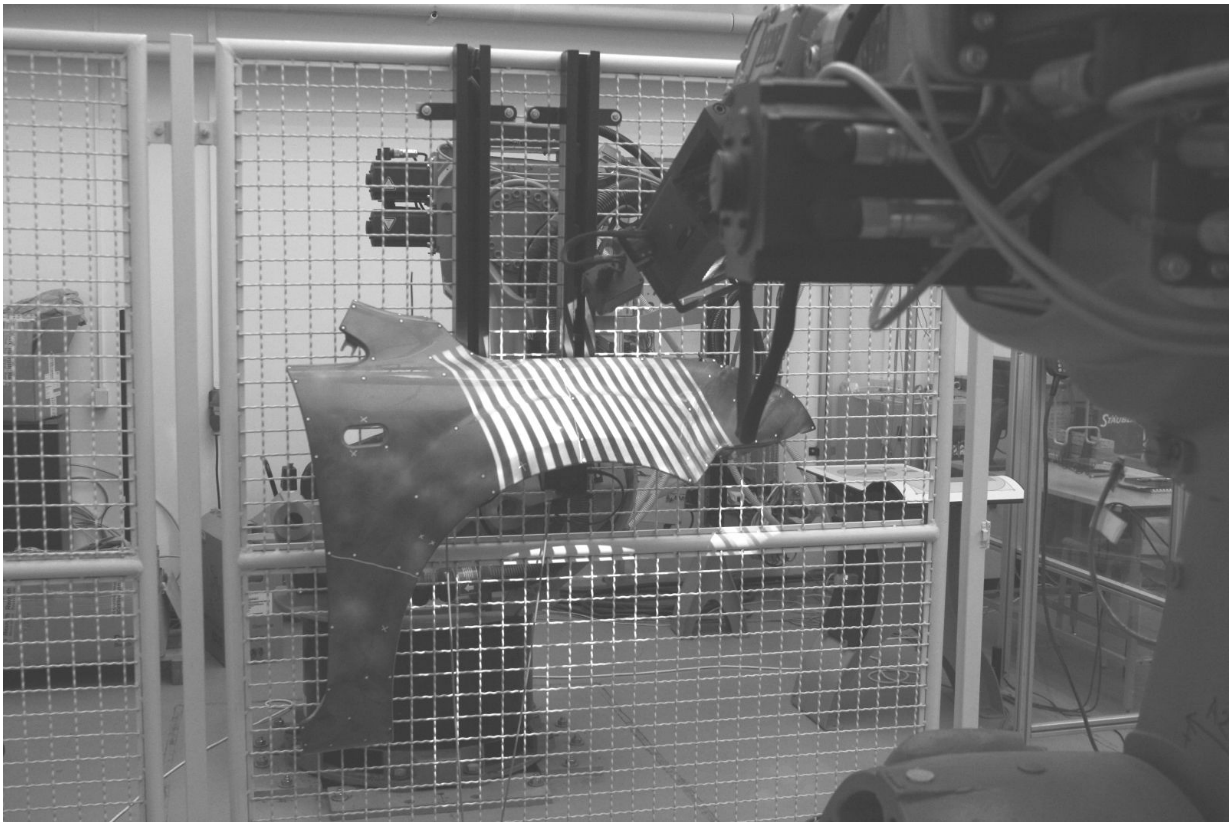

Figure 8 – Automatic scanning process performed by the industrial robot Kuka KR30

Adapting the genetic algorithm for application purposes, a crossing operator has been individually developed, providing for a possible setting of input parameters including: the number of individuals in a generation, the number of generations and the probability of mutation. The possible initial optimization using the nearest neighbour method has also been accounted for.

The procedure, depending on the complexity of the scanned model's geometry, allows shortening the total scanner travel by almost three times, compared to non-scheduled data. To be able to position the scanner precisely, the robot must have its global coordinate system linked with a local system determined by the calibration cross. Before the final creation of the robot control program its planned movements are visualized by loading paths geometry data into the CATIA system (Fig. 7). This method allows to protect against possible scanner collisions when scanning the test object.

The system must be calibrated before the scanning procedure is launched, i.e., the system's position and orientation in the global robot system must be determined by indicating the origin of the local coordinate system and X and Y axis. To do so, the robot is set up using a manual control system so that a selected, characteristic point of an actuator covers the points of the local system.

The method is accurate enough for scanning with the use of a robot. Also the tool – the scanner – must be calibrated. The origin of the tool's coordinate system of the tool is located in the intersection of the optical axis of the projector and the frontal scanner plane. Points generated by the application are later loaded to the Matlab environment where they are converted into coordinates, using a homogenous transformation matrix typical for the robot controller. In case of the Kuka robot, a frame describing the tool (gripper) position includes an X, Y, Z position vector and A, B, C angles of rotation around the individual axis.

After the set scanner position is reached, the user calls up a single scanner shot remotely, while the scanner travels to the next position under the control of a Matlab script. 14 single measurements have been taken for the fender presented in Figure 9.

3.4. TEST RESULTS

The scanning procedure produces a 3D fender model in the form of a triangle mesh (Fig. 9). Figure 10 presents the model generated by scanning by the use of a scanner fitted on a stand. Some missing surface fragments can be seen in hard-to-reach places. They result from the robot's constrained operation area, limiting the size of the scanned object and access to points which require the actuator to be rotated out of the range of the axis of rotation. Large-size objects can be moved against the robot, maintaining the global coordinate system in the same position, with calculations made again in the application.

4. CONCLUSIONS

An innovative concept of the automation of a three-dimensional scanning process using structured light projection technology has been presented, along with its implementation using well-established industrial equipment and control software. The significant shortening of the entire scanning procedure which results from cutting time needed by the operator to move the scanner to the next position, is undoubtedly the biggest advantage of the described method.

In the presented example of the fender, it took the operator almost an hour to scan the fender using a scanner fitted on a stand, while it took only about 10 minutes to scan it using the robot. The labour intensity required for preparing the scanner and the object for the scanning procedure is similar in both cases (positioning markets, tarnishing, selecting the appropriate field of measurement, calibrating the scanner).

Figure 9 – 3D fender model scanned using the described method

Figure 10 – 3D fender model scanned using the standard method

The described method requires additional photogrammetric measurements, but these take a little time only, thanks to the online analysis of the consecutive pictures straight after sending them to the system (less than 10 minutes in case of the fender) and, in case of large objects, are also necessary in the traditional method.

Moreover, the spreading of the cloud of points itself and its analysis in the described application is not time consuming. The longest time is spent on the robot preparation – defining the origin of the global system of coordinates, and the tool (scanner). This procedure, however, is carried out only once for a given setting of cross which determines the system.

At this point of time, the authors do not know any similar 3D-scanning automation solution which is comparable in ease of implementation, cost and efficiency. They are now working further on the described method to use a turntable allowing to apply the entire scanning procedure for medium sized objects and thus to extend its functionality.

5. ACKNOWLEDGMENTS

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