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APPLICATION OF CLOSE-RANGE PHOTOGRAMMETRY IN REVERSE ENGINEERING

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Abstract: *Photogrammetry is a technique which allows acquiring digital representation of a real object (in a form of point cloud) using only a camera. This paper summarizes research aimed on developing a practical application of close range photogrammetry in reverse engineering – for making models of various sized objects, especially mechanical parts. Methodology of creating point cloud basing on photographs was also presented. Acquired point cloud can be used for aiding and simplifying a process of 3D scanning. It can be also used to quickly build simple models for dynamic Virtual Reality simulations and presentations, especially for collision mapping. Furthermore, basing on point cloud, a full 3D CAD model of desired object can be developed and then produced using Rapid Prototyping techniques.*
Application of photogrammetry in reverse engineering brings a number of benefits, including decrease of a time needed to prepare 3D model and reducing price and number of equipment needed to accomplish the task of reverse engineering.
Key words: photogrammetry, reverse engineering, point cloud, shape modelling

1. INTRODUCTION

Reverse engineering is commonly comprehended as a research process of an existing product (device), aimed at obtaining precise data about its traits, dimensions and principles of operation. Reverse engineering of machine assemblies and parts is usually applied when there is a need of re-creating a physically existing device or its part because of partial or total lack of related documentation or digital representation.

Also, there is an area of engineering activities, where the shape of the future product is hard or impossible to determine unambiguously. Following products may be considered as examples: castings of statues, car body parts, ergonomic handles etc. In such cases, item form is specified without using standard geometrical elements. Describing geometrical features of such an object by technical drawing is impossible and creating a 3D CAD model could be very difficult. Possible solution of this problem is manufacturing physical hand-made model as a representation of design ideas. [4] Thus, one of reverse engineering applications is also digitization of this type of products.

Creating a digital representation (mostly 3D model) of desired object basing on series of measurements (performed with manual or automated measuring instruments) is the simplest reverse engineering technique. However, if geometrical features of an item are too complicated, plain measurement techniques can not provide enough data for making a model.

For re-creating shape and surface of close-range objects, optical scanning based on structural light and laser scanning methods are used nowadays. [2] These are very precise methods (accuracy of 0,02mm) but generally unavailable for most companies, mainly because of excessive costs.

Not always level of accuracy achieved with these techniques is necessary. If high dimensional accuracy is not strictly required and simplified approximation of shape can be accepted, photogrammetric analysis (nowadays used mostly for architectural objects archiving) can be low-cost alternative to previously mentioned methods. Just like 3D scanning, photogrammetric analysis produces point cloud as an result yet with much less points. Still, in proper conditions it is just enough to build a simplified model of examined object. This model has lots of applications, described wider in the further parts of the paper.

2. PRINCIPLES OF PHOTOGRAMMETRIC ANALYSIS

2.1 Photogrammetry

The term "photogrammetry" originates from connecting three greek words: *photos*, meaning light, *gramma*, meaning record and *metreo*, which means measurement. Hence photogrammetry can be explained as a technique that handles processing of photographic images, giving dimensions, shape and location of photographed objects as the final result. [1]

Nowadays close-range photogrammetry is used mostly in topography (for terrain mapping), also in architecture for building archiving. [3] Wireframe models of architectural objects are created using this technique (basing on contour outlining on photos). They can be later post-processed by deploying surfaces and adding textures for a better visual effect.

Re-creating object using photogrammetric analysis is a sequence of operations performed in stricly determined order. In research processes described in this paper, EOS Photomodeler software was used to carry out the analysis. Consecutive stages of the process are presented in the next part of this chapter.

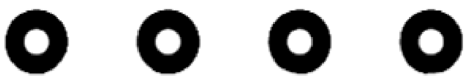

Fig. 1. Markers (targets)

a) b) c)

Fig. 2. Coded targets, a) 8 bit, b) 10 bit, c) 12 bit

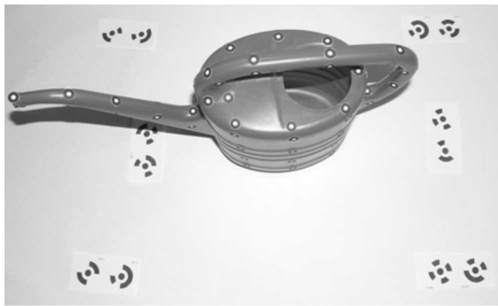

Fig. 3. Scene arrangement: item with markers placed between coded targets [1]

2.2 Object preparation, scene arrangement

The first step is preparation of examined object. It is accomplished by deploying special markers (fig. 1) on object in purposeful manner. Finding proper strategy of marker deployment is an important matter – it helps to find an optimum between amount of work put in item preparation, time of calculation and detail level of result point cloud.

The second stage of the analysis is scene arrangement – placing object between special coded targets (fig. 2). Using these symbols provides the possibility of automatic mutual photograph orienting during the later computing. Every coded target, thanks to its shape, has unique digital representation, recognized by software tool.

Sample model, placed on arranged scene, ready for photographing is shown on fig. 3.

2.3 Camera calibration

Calibration of non-metric digital camera can be carried out in Photomodeler software. Basic parameters of the camera include:

- focal length (c_k)
- lens distortion (radial and de-centering)
- principal point coordinates $O'(o_x,o_y)$
- size of imaging sensor [1]

Calibration process is conducted by taking 12 photographs of a special grid pattern, containing 96 markers and four 8-bit coded targets distributed evenly on flat surface [1]. Photos are imported into Camera Calibrator software and processed automatically to calculate needed parameters. Resulting data file can be saved for use in all further projects using that camera. Also, a self-calibration of camera is possible in Photomodeler. This is a process of fine tuning an existing camera calibration during the processing of a standard project.

2.4 Taking photographs

Photographing the item is the key stage of whole process. Appropriate preparation of measuring environment can greatly improve correctness level of later recognition of markers and coded targets during computing phase. White fabric can be placed around the photographed scene, to avoid catching random points that might be detected as markers by the program. To provide suitable sharpness of images, use of stabilizing device like tripod is recommended if possible [1]. The scene should be illuminated properly, but in a way to avoid light reflexes and shadows. If object surface is glossy, it should be covered with special removable matting powder before taking photographs. Photographs should be shoot in a way to include as many markers and coded targets in one picture as possible. Photographs should be taken in series under different view angles. To properly re-create geometric features of object shown in fig. 3, 39 pictures were taken under three different angles (75^{o}, 55^{o} and 35^{o} between scene plane and imaging surface plane).

2.5 Photogrammetric analysis

The next step is uploading taken photographs and calibration data file to the program. Subsequently, certain parameters like approximate size of the scene, type of coded targets used and size of markers on pictures must be put in. After setting all necessary parameters the program starts the procedure of recognizing coded targets and markers along with automatic photograph orienting. The procedure ends with calculating range of total error, which determines correctness level of the process (perfect for values less than 1, acceptable between 1 and 5, unacceptable for values higher than 5). [1] As a result, point cloud is created (fig. 4).

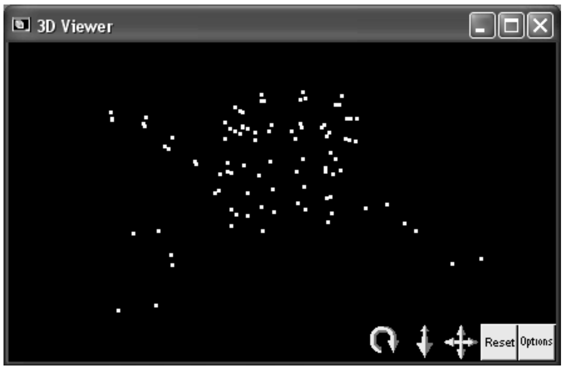

Fig. 4. Point cloud acquired from object photographs.

2.6 Surface deployment

The final stage of object geometry re-creation is using the point cloud for making surface model (which can be later transformed to solid model if necessary). It can be done using Photomodeler built-in tools (resulting model shown on fig. 5) or by exporting point cloud to one of standard file formats, for using surface modelling modules available in professional CAD systems, like CATIA from Dassault Systems company. The point cloud itself can be also used for aiding the process of 3D scanning - it is described in further part of this paper.

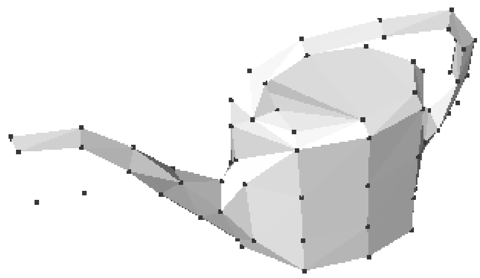

Fig. 5. Surface model basing on the point grid, created with Photomodeler built-in tools.

3. APPLICATION OF DIGITAL MODEL ACQUIRED BY PHOTOGRAMMETRY

3.1 Support of surface modelling for rapid prototyping and manufacturing

In design process involving reverse engineering, it is occasionaly necessary to quickly produce several instances of re-created object for visual purposes and also as functional prototypes, for undergoing various tests.

Also, it is often required to manufacture small series of final products - for example to replenish an assortment of spare parts for discontinued products. Costs of making a new tooling in a conventional way is significantly too high in that case. The problem gets more complicated when there is no digital representation of the object.

Rapid prototyping (RP) techniques are well suitable for above described purposes, because they are capable of generating physical models with no tooling, directly from CAD model. The prototype produced using Three Dimensional Printing (3DP) or other RP technologies (like Fused Deposition Modeling or stereolithography) can be used as a model to create silicone mold for Vacuum Casting (VC) process. VC is perfect for making small (up to 50) series of plastic functional parts.

Nevertheless, if prototype manufactured using one of RP technologies is intended to be accurate (in terms of dimensional and shape compatibility with the original part), proper CAD model must be provided. It is thus noteworthy that creating a precise surface model congruent with the original object with aid of photogrammetric analysis data is not only possible, but also much easier, as opposed to creating the model without help of any automated object mapping technology.

Deployment of surface between points in the point cloud acquired from photogrammetric analysis can be easily done in Digitized Shape Editor module of CATIAv5 software - as it was made during described research.

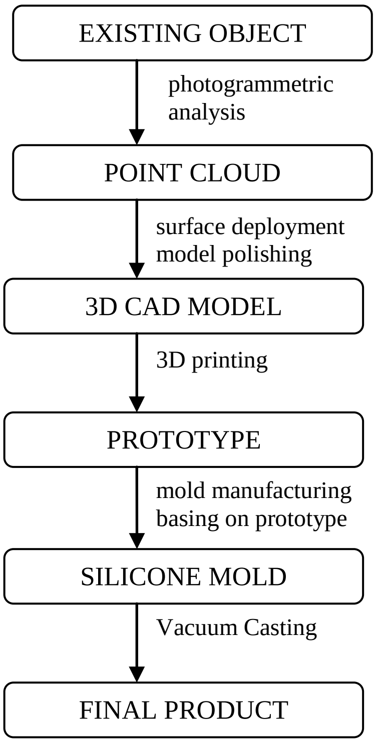

Fig. 6. Reverse engineering process involving photogrammetry and rapid prototyping techniques

Technological process of exemplary product lacking digital data and documentation was presented on fig. 6. The object is a plastic panel used for decorative purposes in public transport buses. The company using these panels ordered several pieces of the product, to use as visual and functional prototypes. However, no documentation was provided, because the company did not have any. Additional requirement was short time of delivery.

The first step was photogrammetric analysis, carried out in a way described in previous chapter. Acquired point cloud (fig. 7) was exported to IGES file format and uploaded to CATIA.

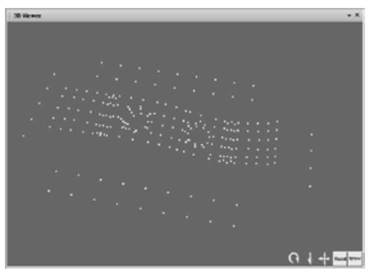

Fig. 7. Point cloud of examined object.

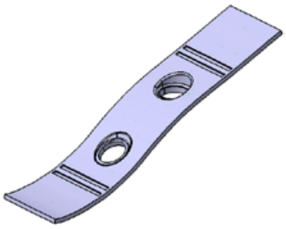

Fig. 8. 3D model created basing on point cloud

Basing on the points, a surface model was created and then transformed into solid model. It was processed to be as exact and accurate as possible. Result model (fig. 8) was then used to produce a prototype in 3D Printing technology.
Created prototype was used as a base model for creating silicone mold for Vacuum Casting process (fig. 9). Several pieces of re-created part were then manufactured using Vacuum Casting. The final result was a complete set of parts, ready for use.
Conclusion of the research is that re-creating a small series of existing part without having any additional data does not cause any problem. Used technologies (photogrammetric analysis and rapid prototyping techniques) allow producing such series of parts with a very low budget and in a very short time (in described case time of delivery was lower than 5 days). Whole procedure also does not require special qualifications, every stage is simple and easy. It is remarkable though, that the same procedure applied to more complicated part (especially with lots of curved surfaces) would probably not give such good results. Because of insufficient data provided merely by photogrammetry, it could be impossible to create an exact 3D model.

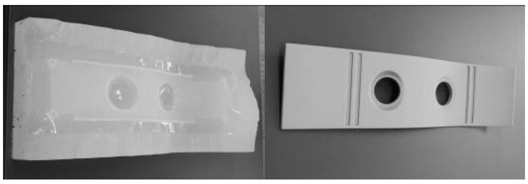

Fig. 9. Half of silicone mold and final product made with Vacuum Casting

3.2 Support of 3D optical scanning process

When object geometrical features are very complicated or high level of accuracy is required, photogrammetry itself is not enough to create 3D model fulfilling all of requirements. It may become necessary to use professional technology of digitizing – optical scanning using structural light.
Photogrammetric analysis may be efficiently used as a supporting process, carried out before performing 3D scanning operation, especially in measurements of large objects. In that case points obtained as an outcome of photogrammetric analysis are used as referring points, helping to put together subsequent scans.
That application of point cloud created with photogrammetry helps to significantly reduce time dedicated to creating object model using 3D scanning. Currently further research is conducted in that direction - aimed at optimizing number of photogrammetric measurements and strategy of marker deployment on examined objects.

3.3 Approximate model development for virtual reality

Virtual reality (VR) is a group of modern computer technologies associated to create possibility of generating interactive, three-dimensional and realistic virtual environments. VR can be applied in engineering especially as hi-tech way of design enhancement. Dynamic and realistic simulations involving designed objects can help making easy conclusions about construction optimization.
Integral element of VR is collision mapping. Frequently – especially when simulating robotic cells and assembly lines – a need of implementing work environment geometry into the simulation emerges, to check if any collision occur during robot operation. Obtaining 3D models of all objects within range of robot arm could take a lot of time.
Photogrammetric analysis can be used in process of building simplified models of

work environment objects in a quick and easy way. Acquired models can be then used to examine possible collision situations and other interactions. Models build using photogammetry analysis are very rough (especially when scene is not prepared as carefully as when photographing single object), but in this application it is rather an advantage – computers performance is limited, so reducing the geometry of objects involved in virtual simulation to the most simplified representation acceptable is commonly practiced. Collision mapping is actually performed mostly using alternative geometry, usually in a form of bounding box for preliminary check, with more complicated methods (from convex hulls to exact geometry) used only when necessary. Invaluable advantage of photogrammetric analysis in that case is short time of acquiring the 3D model and good visual properties – textures extracted from photos can be applied to improve visual effect.

4. SUMMARY

Close-range photogrammetry allows to obtain digital representation of studied existing object in straightforward way, without using equipment other than digital camera and computer with appropriate software.

Application of object representation acquired during photogrammetric analysis to build model for manufacturing short series of products helps to reduce costs and shortens time of the whole process. Applying photogrammetry for supporting 3D optical scanning brings similar benefits – time reduction and consequently decreased cost of whole operation. Rough model build using photogrammetric analysis has also a number of other applications – it can be used in virtual reality as a representation of existing object which may collide with other objects. It is not difficult to find other applications of such model, also in disciplines other than mechanical engineering.

Present-day market trends force companies to use lean production methods and constantly shorten delivery time. Thus simple, inexpensive and easily accesible photogrammetry is worth of interest.

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