

The Obtaining CAD Models from Point Clouds of Curvilinear Object Images

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Abstract—The purpose of this study is to develop a system capable of interpreting the images of objects taken with a digital camera for obtaining 3D point clouds, and further rendering such 3D point clouds into surface and solid models with a design software. The software analyzes, on pixel basis, the images obtained with a digital camera naturally, without the need to a special shooting setup. These analyses are performed by the user in the area defined by reference points on the image. By interpreting the defined region with pixel values, one can swiftly obtain 3D point cloud of the object in the marked area. Furthermore, in the study, a different approach, involving image processing, is presented for reverse engineering applications in 3D design and manufacturing process. In this study, presented as a reverse engineering application, algorithms employed by the system for image processing are described on a sample image, and some sample images processed in the system are provided in combination with the point cloud and the solid model. These instructions give you guideline for preparing papers for IJSER JOURNALS. Use this document as a template if you are using Microsoft Word 6.0 or later. Otherwise, use this document as an instruction set. The electronic file of your paper will be formatted further at IJSER. Define all symbols used in the abstract. Do not cite references in the abstract. Do not delete the blank line immediately above the abstract; it sets the footnote at the bottom of this column. Don't use all caps for research paper title.

Index Terms— CAD models, image processing, pixel detection, point cloud

1 INTRODUCTION

ENGINEERING is a process involving the stages of drawing, production, assembly and system development. There are two types of engineering: advanced engineering and reverse engineering. To detail, forward engineering is the traditional process of starting with high-level abstractions and logical designs and then ending up with the physical implementation of the system. However, in certain situations, a physical part/product may have no technical details, such as drawings, bills-of-material, or any engineering data. The process of replicating a part, subassembly or product without the help of drawings, documentation or a computer model is known as reverse engineering [1]. Alternatively, reverse engineering can be defined as the process of obtaining a CAD model from 3D point clouds by digitizing the pieces. On the other hand, researchers may adopt different descriptions for reverse engineering (RE) according to their specific areas of work [2]. In one study RE is defined as "the basic concept of producing a piece based on an original or physical model without the use of an engineering drawing" [3]. According to Yau et al., RE is the process of creating a new geometry from a piece produced by modifying and digitizing a CAD model. Moreover, developing image-processing applications is known to be a highly complex and time-consuming effort. Therefore, this hinders the marketability of such applications. On the other hand, demand to solid applications is growing in all markets: medicine, biotechnology, remote sensing, astronomy, ecology, security, forensics, chemistry, surveillance, quality control, etc.

As a result, developing systems that can help end-users build customized applications is increasingly becoming important [5]. The main aim of image processing is identifying the image to obtain useful information about the scene, and to observe the image well. Here, the observer is human or machine. If raw image is not clear enough, it must undergo a series of specific processes. Such processes are performed electronically and mostly manually, however there is need to optical and electronic devices to obtain the image. Where digital image processing is employed, many advantages such as speed, low cost and successful result are yielded.

Previous studies reveal that various parameters such as camera quality, calibration, shooting setup and auxiliary shooting tools effect the digitizing and processing of images. In interpreting the images of an object, auxiliary tools such as grid pattern or object marker are the most common. Generally, special shooting setups are used to obtain computer-aided design models of objects, and also to produce 3D motion parameters. Additionally, in reconstruction procedures using markers on the object, and particularly in architectural restoration, only the 3D models of the object front side can be obtained.

Many of the studies on image processing focus on object recognition, camera calibration, 3D reconstruction, and developing different methods and algorithms for computer vision. In their study, Benlamri and Al-Marzooqi [6] describe object description and 3D modelling methods where images of coloured, sequential and free-view objects are used. In this approach, producing the combination of edge and region data, use of algebraic closed surfaces, and surface definitions are addressed. In another study, Byne and Anderson [7] devel-

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oped a CAD-based computer monitoring system. In this system, by defining 2D objects being originally 2D that can further be represented in 3D, a visual power is created, allowing to obtain 3D geometric models via common computer software. Reed and Allen [8] proposed a method for solid model construction from consecutive images of an unknown object. In this method, models containing row data of each image are used on the mesh surface to represent the solid model. Kimber and Blotter designed a method for identifying different contours between digital and physical objects with a square interferometer. This method is characterized as a tool for measuring displacement. In this method, a light source and a grid pattern are projected onto a test piece via a lens. Based on the grid-pattern image obtained, the CAD model of the object is produced. Shootings are made at a special setup, using a grid pattern as the auxiliary tool. And according to the grid pattern, camera is calibrated and coordinates are detected [9]. Hua and Weiyu proposed a new approach using 3D library support. The approach uses image-based architectural modelling to process the images. Specifically, digital 24-bit 1024x768 images with BMP extension, and a model library to create a 3D realistic model are used [10].

In their study, Lee et al. developed 3D human face modelling, using perspective images in combination with a contour-based general model. In this work on virtual reality, human head model is realistically created 3D, and an effective method is developed using the perspective obtained with the images of the 3D human model from different angles [11]. In their study, Tubic et al. performed 3D surface modelling from individual object curves in the image and these curves belong to free-standing objects [12]. In his study, Zhou used model-based matching algorithm for chart recognition in computer-aided design and photometry measurement systems. The approach underlying the study comprises the rendering angle, the graphical angle and model matching [13]. In their study, Sturm et al. attempted to estimate camera's focal length from photographs, both shot with a constant focal length during camera motion. In this approach, Kruppa equations are used [14]. Boufama and Habel developed a 3D reconstruction model without a camera calibration. In this model, the image of the 3D Euclid structure is obtained without need to a precise estimate of actual parameters. The approach is implemented in three steps with simplified Kruppa equations [15]. Dornakai and Chung presented an algebraic approach for automatic camera calibration. For shots with a single camera, the study introduces new restrictions with respect to internal parameters such as camera resolution and sensor as much as rotary motion is concerned [16]. Mülâyim et al. implemented a silhouette-based 3D model construction using multiple images. In the study, a special shooting setup with appropriate illumination is used to implement 3D reconstruction of real objects [17]. Grossmann et al. developed algebraic ratios for 3D reconstruction of image structures having one or more views. In this study, they use 2D points derived from images having one or more views and implement 3D reconstruction accordingly [18]. Gaspar et al. proposed a new method for an interactive 3D reconstruction of structures, using multi-directional images obtained from different directions [19].

Fruch and Zakhor created a model for cities by using 3D aerial photographs and ground-level laser beams. In this study, 3D models of urban areas were created by means of auxiliary tools such as 2D laser scanner and traffic cameras [20].

There are many approaches for creating 3D city models. In one study, objects in images obtained via satellite or antenna are detected by stereo vision or synthetic-aperture radar algorithms. Though the approach allows rapid acquisition of objects, model resolution and accuracy are very poor [21, 22]. Another study, where a wheel robot is equipped with a laser beam and cameras, is aimed at collecting image data for the entire city. In the system created for this study, a huge period is needed to obtain data, and also reliability of such autonomous mobile systems in non-structured environments is also poor [23, 24]. In their study, Bleser et al. introduced a real-time 3D camera surveillance system for industrial augmented reality applications. This solution avoids typical functions of location engineering such as prediction, exposure, monitoring systems and landmarks [25].

Augmented Reality (AR) offers new approaches in areas such as machine repair, design, medicine and cultural heritage [25-28]. Song and Wang [29] developed a new grid-matching method for 3D reconstruction. Automatic 3D construction of surfaces has long been the subject of research in the field of digital photometry. Today, photometry is employed in the areas of computer vision and computer graphics as well as industrial supervision and reverse engineering [30, 31]. Reconstruction of 3D models involves four main steps: data capturing, recording, surface integration and texture mapping. Partially formed 3D shapes and texture data are obtained from different angles of view [32]. A study was performed on local morphology, using field applications, computer vision applications and image processing applications [33]. Computer vision and image recognition are active areas of research linked to incremental number of images, image quality, detection of objects in the image, and associated applications [34, 35]. Barbero and Ureta [36] compared five digitization techniques in the field of Reverse Engineering in terms of the quality of the distribution of points and triangular meshes: 1. An ordered point cloud obtained with a laser incorporated in a CMM; 2. A disordered point cloud obtained with a manual laser, the position of which is determined with a Krypton Camera; 3. An Exascan manual laser with targets; 4. An ordered point cloud obtained by high precision Computerized Tomography (CT); 5. An atos fringe projection scanner with targets. Zhao and Li [37] developed a 3D object pose estimation method for an automated manufacturing assembly process. Their experimental results show that the 3D pose estimation method produces accurate geometrical information for an automated material handling application. Bosche [38] presented a new approach for automated recognition of project 3D Computer-Aided Design (CAD) model objects in large laser scans. Test results were given with data obtained from the erection of an industrial building's steel structure. Yang et al. [39], in their study, presented a fast and precise 3D laser scanner to retrieve point cloud data and then import the data into Rapidform XOR2, an application used in reverse engineering, to process point cloud

data and construct 3D models. Their study results were converted from 3D models into 2D pictures by parameterization software Pro/ENGINEER to provide designers precise and realistic dimensional data, which efficiently reduced time in cartography and increased historic building dimension precision during digitalization.

The purpose of this study is to develop a reverse engineering application that processes colour images, obtained naturally with web cameras, camcorders and digital cameras, and then further to obtain a 3D point cloud, without the use of typical location engineering functions such as special shooting setup and object markers. In developing the intended system, the .NET programming infrastructure and PHP coding language were used. In this system (Fig. 1), colour images of sample engineering models were processed to obtain 3D point clouds, which were then converted into solid models in a design software to perform 3D reconstruction of the objects.

Here, pixels in the image are scanned and identified according to their colour values, converted into a binary code, and then temporarily stored in the file in the form of an array composed of 0s and 1s. When colours are scanned pixel by pixel, colour values within the +12 and -12 RGB range are considered same. For example, if the first pixel has a colour value of (235, 39, 84), then the system considers successive pixels within the range up to (223, 27, 72) same (Fig.2)

As images are assessed based on colour values, assessing an entire image takes a long time. Therefore, as shown in Fig. 2, the user uses the mouse to assign reference points to the target object in the image. The area enclosed by these reference points on the image is processed. This helps to define object edges as well as shorten the time to obtain points. Here, starting from the first marked reference point, the system scans the defined reference area from left to right. If a conflicting colour value is found, the system automatically executes re-toning. With pixel detection in this colour analysis; images can be interpreted without running a different procedure on naturally acquired images and without the need to special shooting setups.

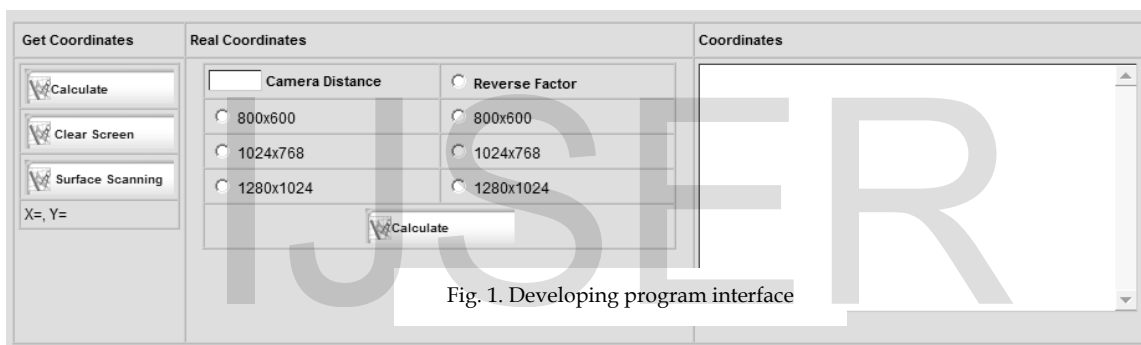


Fig. 1. Developing program interface

2 ANALYZING THE IMAGE

The models illustrated can be represented in two views. Images are acquired naturally without a special shooting setup. The system supports the following formats: jpg and bmp ages (bit depth 24) taken with digital cameras; avi (audio video interleave) videos recorded with handheld cameras; and *bmp*, *jpg* or *avi* images taken with webcams. Before processing, video images are split into frames and converted into the bmp format. The RGB (Red, Green, Blue) colour system is used in obtaining pixel values in the images. To create a colour at RGB standards, a particular mixture of red-R, green-G and blue-B colour codes is needed. In the RGB system, each colour can have maximum 256 values. A total of 16,777,216 colours are generated through the combination of these three colours (256x256x256). These are represented as real colours. For example, a pixel with (178,229,41) colours is represented as (10110010,11100101,00101001) in the binary system. Likewise, the image to be processed digitally is represented by 0s and 1s.

Figure 3 shows sequential procedures performed on the image. These consist of 5 steps. Identifying the edges within the marked area by edge detection, identifying pixels by colour over the whole line marked, verifying edge pixels by comparing pixels to pixels found during edge detection, applying structural elements to edge pixels, and finally, obtaining points from remaining pixels. Pixels within the marked area are identified by colour analysis, and estimated edge boundaries are found. Thanks to edge detection, pixel array on first-degree edge boundaries is also addressed. As shown in Figure 2, reference points are marked reciprocally along the edges of objects in different diameters. Even for different diameters, the system detects pixels crosswise between these marked points. After pixel detection, each reference point along the Y plane, and points found to be adjacent to such reference points are scanned circularly by Y transforms (Fig. 4).

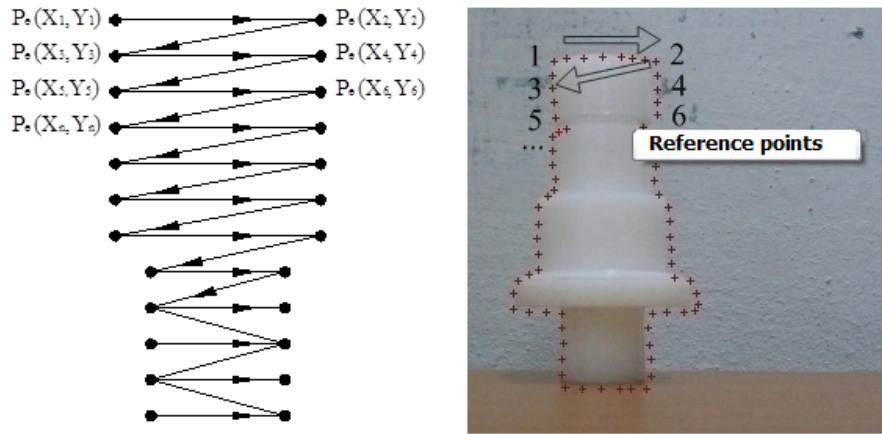


Fig. 2. Colour analysis of the image

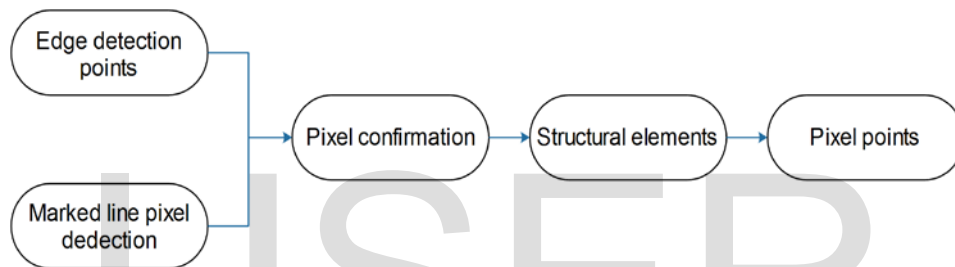


Fig. 3. Procedures performed on the image

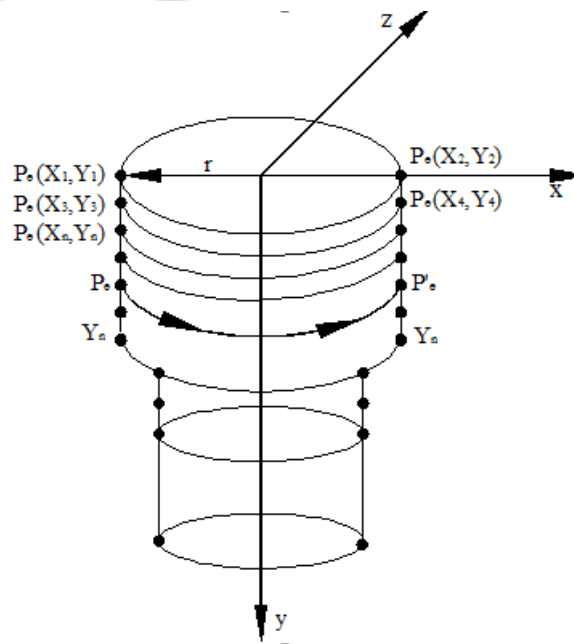


Fig. 4. Pixel scan with Y transforms

Figure 4 shows Y transforms applied to reference and pixel points after pixel detection. Transforms applied to reference

points and pixels adjacent to them start first with point $P_e(X_1, Y_1)$ and continue until lowermost points by Y_n along Y and X value differences between $P_e(X_1, Y_1)$ and lateral reference points, e.g. $P_e(X_2, Y_2)$, and adjacent intermediate pixels also represent the diameter, and hence the transform centre. Moreover, distances between reference points also serve as a diameter value, hence only the single views of the pieces are processed. While applying transforms to intermediate pixel points marked and detected along the Y plane, and while calculating the Z value, the radius value "r", which is not visible in the front view, is used. With Y transforms, pixel scanning is performed 360° around the centre of both points marked horizontally. This transform starts from the first reference point and continues up to lowermost reference points, with all intermediate adjacent pixels included. Pixel points marked and detected on the left side, and intermediate pixels again on the left side are assumed as the starting point for applying the transform over the whole 1-360° range. During this transform, pixels are detected. Second reference points on the right side are used to detect the centre and radius of the circular scan, hence the Z value.

3 OBTAINING POINT CLOUDS

Point clouds are detected based on reference points which are randomly marked from left to right along the edges of the target object in the image. The scan run to obtain point clouds at the end of the analysis is superficial, and slopes on the surfaces are determined according to circular orientations which are at the Z coordinate relative to the X and Y plane in the front view of the piece. In the general point matrix, Z and Y coordinates are exchanged so that the points are distributed along the Y plane. Mathematical expressions are used in Y pixel transforms as follows:

$$Z' = r.Cos\theta - x.Sin\theta \tag{1}$$

$$r = \frac{X_2 - X_1}{2} \tag{2}$$

$$X' = r.Sin\theta + x.Cos\theta \tag{3}$$

$$Y' = Y_n \tag{4}$$

In Eq. (1), Eq. (3) and Eq. (4), the transform of each pixel point is represented in its own plane. Z pixel points are represented by the radius "r" (Eq.2). They are half the distance between two horizontal reference points and each left and right point in the X plane. The circular scan on the Y plane continues by Y_n up to lowermost reference points on the horizontal plane (Fig. 2). Pixel points obtained by circular scanning in Y direction are represented in the transform matrix (Eq.5).

$$\begin{bmatrix} X' \\ Y' \\ Z' \\ 1 \end{bmatrix} = \begin{bmatrix} Cos\theta & 0 & Sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ -Sin\theta & 0 & Cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y_n \\ r \\ 1 \end{bmatrix} \tag{5}$$

In Eq. (5), circular Y transforms of reference and intermediate edge pixels starting with the first reference point are represented in the matrix [41]. In this transform, angle θ starts with the 1st degree and continues up to the 360th degree. When a 360-degree scan is completed for each point pair, an offset by Y_n is applied on the Y plane, and then the circular scan is resumed (Fig.2, Fig.3). Offset distance on the Y plane is determined by reference points. With intermediate pixels identified by colour analysis, a verification is performed to make sure that scan is within the boundaries. Pixel points obtained for each pixel set are temporarily stored in the pixel dot matrix (Eq.6).

$$P_{e(x,y,z)} = \begin{bmatrix} X'_1 & Y & Z_1 \\ X'_2 & Y & Z_2 \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ X'_n & Y_n & Z_n \end{bmatrix} \tag{6}$$

Eq. (6) shows the matrix where pixel values obtained over the whole 1-360° range for each Y_n value from Eq. (5) are stored temporarily from the initial value Y_n up to the final value Y_n . As seen in Eq. (6), for the structural element to be applied to the image, the plane coordinate sequence accommodating the image processing screen is required. Due to circular involvement in the operation at estimated boundaries, unnecessary points along the vertical edge line and around reference points resulting from pixel overflows should be removed (Fig.5). Such removal is performed by applying the structural element to the image based on marked reference points.

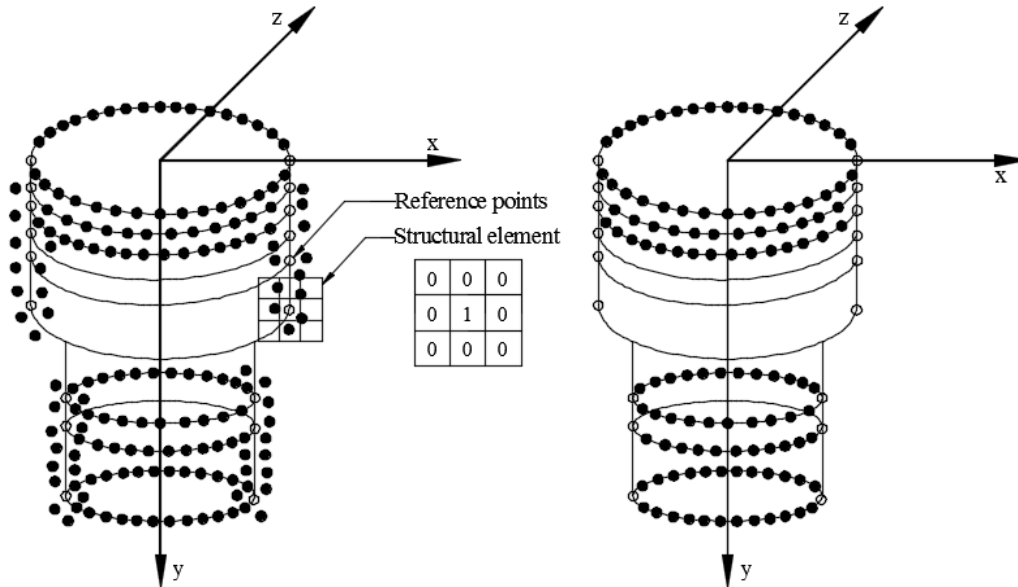


Fig. 5. Applying structural element to pixel points

In Figure 5, structural element is applied, along the edge, to the pixels detected by circular scanning. The structural element is traversed from the first reference point to the last one on each marked reference point. With this traversing procedure, unnecessary pixels around each reference point as well as pixels extending beyond the edge line are removed. While a coordinate matrix is derived from the resulting pixel dot matrix, a further transform is applied between the planes so that Y points replace Z points, and Y points replace X points. The purpose of this procedure is to see the changes in the first two coordinates within the X, Y, and Z coordinate sequence. At the same time, this transform is also necessary for more accurate computation of real coordinates. The coordinate matrix is obtained by replacing X values with Y values, Y values with Z values, and Z values with Y values as yielded by the pixel dot matrix after application of the structural element (Eq.7).

$$X, Y, Z = \begin{bmatrix} X_1 & Y_1 & Z_1 \\ X_2 & Y_2 & Z_1 \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ X_s & Y_s & Y_n \end{bmatrix} \quad (7)$$

Coordinate values obtained from the pixel dot matrix in Eq. (7) are shown in the matrix. During this procedure, transforms were applied to Y and Z planes, and resulting coordinate values were sequenced around the Z axis. Here, there is a circular pixel scan. Therefore, objects processed in the system should be circular. A dual transform is employed in the software because a single view of the piece is used for image processing [40]. By placing a

comma between each element in the column of the coordinate matrix shown in Eq.7, matrix elements are exported to the point cloud file so that the point cloud is obtained (Fig.6).

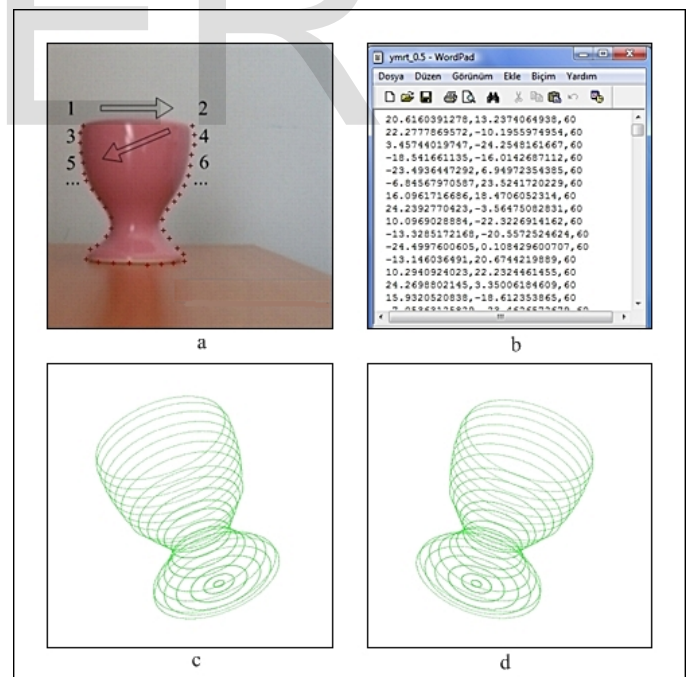


Fig. 6. Obtaining point clouds
 a. Marked reference points
 b. Point cloud file
 c, d. Point cloud

Figure 6 shows the process for obtaining the point cloud from a sample piece. In the view, reference points are marked so

that they represent the piece shown by numbers. As the picture of the piece reveals, upper part of the piece is open while the lower part is closed. In such cases, the closed part of the piece is marked again with reference points. As pixel detection and circular scanning will also be performed in this closed area, this part will be closed as seen in the point cloud. Marking pattern applied to the edge enclosed by reference points is, like overall marking, first right and first left horizontally.

4. CONCLUSIONS AND FURTHER WORK

The program developed in this study is capable of readily interpreting the images shot naturally without need to camera calibration. Thanks to the algorithms developed for image interpretation, point clouds can be obtained for many pieces which can be represented in two views ranging from simple to complex (Fig.7, Fig.8). The number of reference points marked can vary by the processed images. If the number of marked reference points is high, the system has a reduced process time. Time elapsed for obtaining 3D point clouds after reference point marking does not exceed 4 seconds.

Figure 7 and Figure 8 show sample images and point clouds in combination with solid models. Solid models can easily be obtained from point clouds. Such point clouds were first transformed into a surface model and then into a solid model using a computer aided design software. And the process time for producing point clouds is around 2-4 seconds. Sample images were shot in situ under natural light on a smooth surface. The system is capable of detecting the items within the area to be processed in open or closed state, and interpreting the images with the help of reference points, colour analysis and the algorithms developed.

In many studies where digital images are interpreted by image processing, a special shooting setup and camera calibration are used [9, 11, 17]. Camera calibration is performed using techniques such as grid projection and attachment of markers to the target object [29]. Markers are also one of the common auxiliary tools employed in contactless systems which represent a practical field of reverse engineering. Similarly, in other studies, objects in images could be identified by object libraries. Such object libraries are commonly utilized in interpreting objects by comparing them to a similar form [10].



Fig. 7. Point clouds and solid models obtained with the software

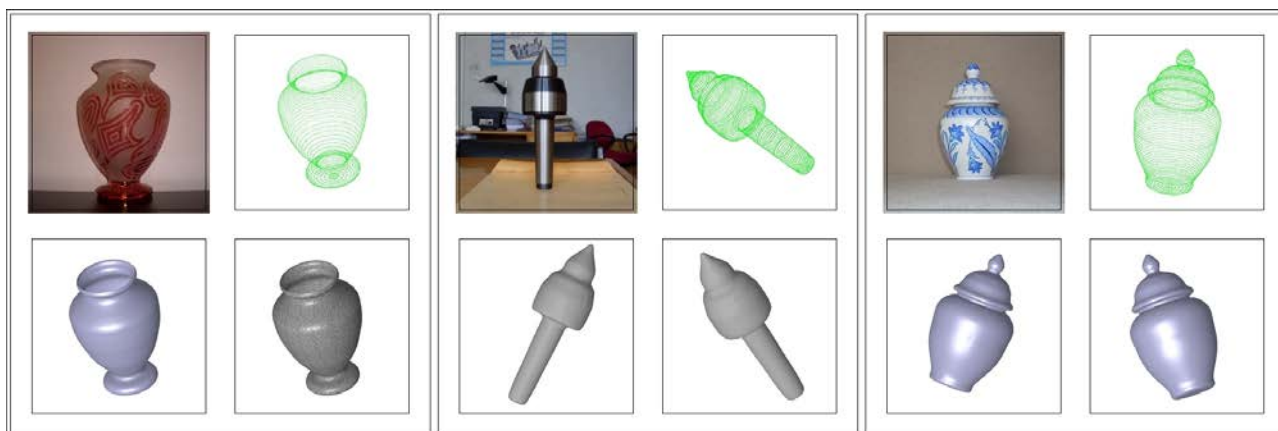


Fig. 8. Point clouds and solid models obtained with the software

Moreover, edge detection algorithms are also commonly

used to determine the target object in 2D [6, 12]. In this study, the need to location engineering parameters such as calibration, exposure, monitoring systems and landmarks was avoided in obtaining 3D point clouds from images.

The software developed offers a novel and distinct approach based on image processing which will contribute to reverse engineering processes in design and manufacturing. Effective use of time for design and manufacturing phases will effectively reduce costs as well. One key reason to use reverse engineering applications is to shorten the design process. Efforts to shorten the time spent on design would enhance production processes. Advantages offered by the system may be listed as follows:

- Point clouds can be obtained from the images of many simple and complex pieces in the system.
- Parts designed on computer or involved in manufacturing can be transferred to the design environment faster, with the option of performing a computer-assisted analysis (static, dynamic) and manufacturing. Furthermore, the model can be exported to rapid prototyping machines for prototyping.
- The system supports images with different resolutions, and resulting point clouds accurately represent the target object in the image.
- By using reference points in the system, the image interpretation area is limited so that only the target area is processed and undesired point clouds caused by background items can be avoided. And this reduces processing time down to 2-4 seconds, and also ensures that naturally acquired images can be processed faster in the system.
- Moreover, by setting a shooting distance in the system, point clouds can be obtained in actual dimensions from the images that can have the resolutions of either 640x480, 800x600 or 1024x768.

By integrating new modules in the system and developing new algorithms, it may be possible to process images with more complex geometries and further to represent them with more views. Algorithms developed in the study, and the image processing method involving colour analysis will be useful for future efforts in this field. No resolution limitation for image processing in the system will allow high-resolution images to be processed in parallel to the advancing technology. In the next study, aim is to obtain 3D point clouds from object images of more complex forms by introducing new modules in the software.

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