3D scanner, automatic registration,
surface merging

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AUTOMATIC REGISTRATION AND MERGING OF 3D SURFACE SCANS OF HUMAN HEAD

The article presents a method of registration of 3D surface scans obtained from different viewpoints and a method to merge them properly into one 3D photograph of patient head for orthodontic diagnosis. Our task concentrates on obtaining automatically the precise and repeatable examination results. So far methods of registration and merging range images into a 3D photograph was performed semi-automatically by a qualified person. The presented method is automatic and based on the analysis of redundant and uncertain data.

1. INTRODUCTION

The development of surface scanning systems designed mainly for the industry sooner or later will lead to application of this technique for medical purposes. But before this technique can be put into practice its accuracy must be tested, parameters of systems for 3D scan acquisition must be established and procedures for further data processing must be determined in order to assure precise and repeatable examination results. Finally potential applications of this methodology should be considered and a relevant computer system implemented. The examination results of scanner accuracy, and the scanning procedures of patients were presented in [1], the possible application in facial feature analysis was shown in [3], the implementation of a computer system for scanner supported orthodontic diagnosis is described in [4].

So far the process of registration and merging scans into a 3D photograph was performed semi-automatically by a qualified person. The main task of the person was to choose the most reliable points and faces on each scan obtained from a single direction. This tiresome process was followed with registration and merging of scans and then visual verification of the yielded shell was done. When the merged surface occurs folding, faulty or too much holes appears the whole process had to be repeated. Even if the results are acceptable the repeatability of the process cannot be guaranteed. In the article we present a automatic method for registering and merging range images of human head into 3D photograph.

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2. SCANNING DEVICE AND TECHNIQUE OF 3D SCANNING

Conditions for scan acquisition system should be considered before preparing the algorithm of automatic registration and merging of range images. Minolta VI9i scanner with lens of focal length 14 mm (MEDIUM) and workstation with RapidForm software were used in IITIS PAN to facilitate the scanning of patients [1]. The scanner can only obtain data of these surfaces which are visible from its observation point. In order to scan the whole object it must be rotated. Scanning of inanimate mater can be done with a rotary table. The information of table rotation is used to find initial positions of each scan in further procedures of data registration. But, when we scan human faces or, moreover, child faces it is important to stabilize a patient position. That is the reason why we decided to move the scanning device around the patient whose position remains unchanged. One of the system parameters is the number of scans which should be acquired. The article [1] concluded that the best way to obtain full coverage of the human head is to choose 7 observation points placed evenly on the observation circle as shown in fig. 2. Such number of scans yields some redundancy but assures that each important part of the face surface is scanned.

Fig. 1. Positioning of the observation points

3. AUTOMATIC SURFACE INTEGRATION

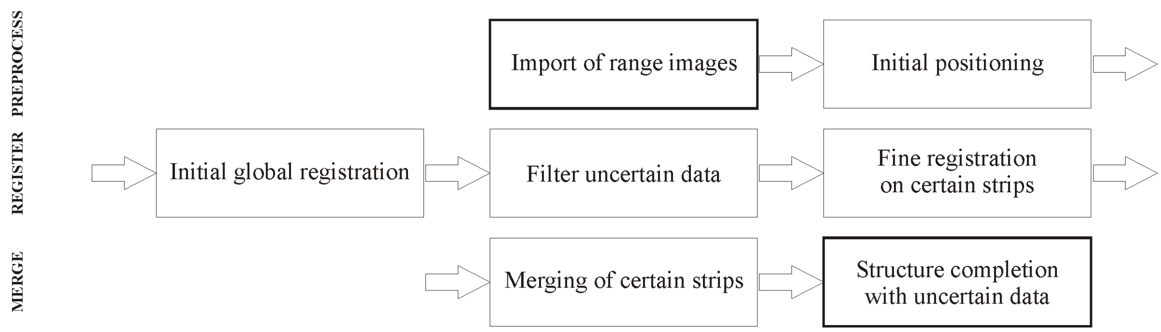


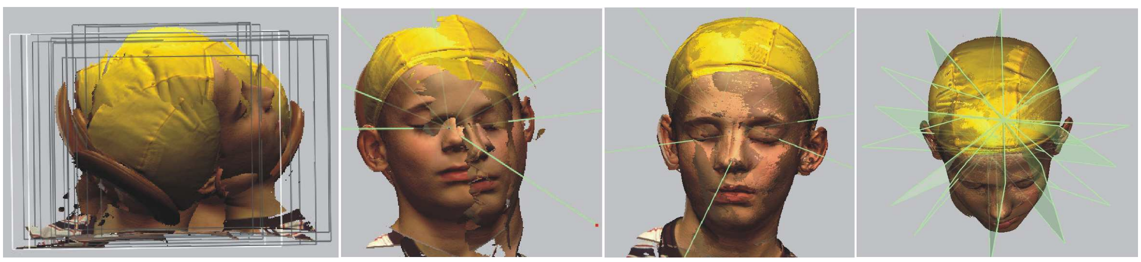
Fig. 2. Surface integration from range images to merged surface

The process of surface integration begins with import of range images directly from the scanner device (see fig. 1). Then the initial positioning using the prior information about the device alignment is performed. Additionally the main axis of rotation and a global location of observation points are roughly predicted. After that the roughly positioned scans are initially. The initial registration makes it possible to calculate fine positions of the observation points as well as the main axis of rotation. The next step is filtration of the registered range images and segmentation into discrete parts – strips – depending on the surface reliability. Only the most reliable strips are taken into the fine registration in the way to have the whole object covered. After the fine registration we add pieces of less reliable strips into not covered places of the registered reliable mesh so that we obtain the structure completely covered with surfaces (as far as there is enough input data to cover the whole object). The final task is merging the registered and fulfilled meshes into one shell.

4. INITIAL POSITIONING OF RANGE IMAGES

There are two operation strategies of Minolta VI9i scanner. The first one is operation with a rotary stage. The scanner has a stable and calibrated position then so it is easy to calculate the axis of rotation and the angle between the following range images is set as an output of the stage controller. These values makes it possible to calculate the initial transformation of an object on the rotary stage to the global coordinates. The transformation compensating the rotation of the stage is done by the scanner software itself so the obtained range images can be easily registered. Unfortunately the usage of the rotary stage in case of patient scanning is not possible because of relatively large size of the object (a patient) as well as vibrations of the moving stage which often made the patient change his position during the examination.

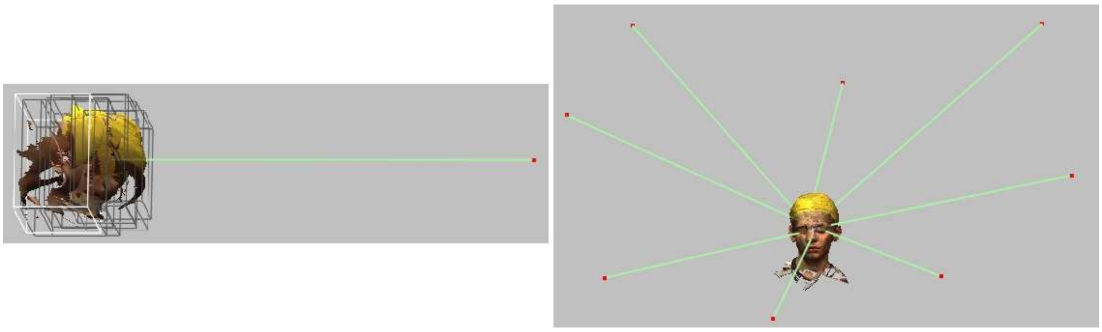
The second strategy assumes that the object does not move, but the scanner changes its position. The range images are stored in their local coordinate systems (fig. 3a). The registration of such structures are tiresome as the automatic registration procedures usually limit the range of searching for similarities on surfaces. So we need to initially position the range images before the first registration.



a) b) c) d)

Fig. 3. Range images: a) imported from a scanning device, b) initially positioned, c) initially registered, d) divided by threshold planes

As an entrance to the registration process we have 7 shells. Initially we establish the approximate position of each shell in the global coordinate system. There are some assumptions done for the scanning process and they are used to initial positioning of shells. Scanner device has a fixed vertical angle (nodding movement) to the value about $\beta = 30°$. It is also assumed that scans are acquired around the object with the horizontal angle $45°$. The fourth scan gives the frontal part of the head (see fig. 1), hence the horizontal angle can be calculated as $\alpha_i = i \cdot 45° - 135°$, where $i = 0 \ldots 6$ are stages of the acquisition process. At the beginning the scans are given in local coordinate system whose origin is located in the observation point of the scanner device $C_l = (0,0,0)$ and the scanning axis is specified by vector $O_l = [0,1,0]$ (fig. 4a). For each range image S_i its intersection with the scanning axis O_i is specified as $D_i = O_i \cap S_i$. There is another parameter which supports calculation of the rotation centre in the global coordinate system, it is radius of the patient head. We pick its value experimentally between 6 cm for children and 8 cm for adults. Under such assumptions the system can automatically distribute the scans in the global coordinates (fig. 4b) as well as calculate the main rotation axis and draw the scanning axes which connect the rotation centre and the location of the scanner viewpoint. The main rotation axis is calculated as a resultant of vector products consisted of the neighbouring scanning vectors and the middle of rotation is established in the averaged convergence point of the scanning vectors. In this way we obtain the rough transformation of the range images (fig. 3b) and that is enough to do the proper initial registration (fig. 3c).



a) b)

Fig. 4. Scanner locations in relation to range images: a) just imported, b) initially registered

5. REGISTRATION OF RANGE IMAGES

There are two different approaches to register range images: sequential and simultaneous. First approach considers on two range images at a time and the registration process is performed for successive pairs of range images that are overlapped in space. The sequential registration is repeated until all images are used. After each partial registration the position of the registered structure is fixed. The simultaneous approach involves all range images in the registration process at one time. The registration error is diffusively distributed over all overlaps of each range image. The disadvantage of the first approach is that the registration error, introduced due to data noise, is propagated and accumulated in the next steps of the process, but in case of registration of a few not noisy range images it can be effective.

The registration uses points as matching units with the point-to-point distance metric [2]. Basically the algorithm uses a framework of the pairwise ICP algorithm. The aim is to minimize globally an objective function for each pair in case of sequential approach or for all range images in case of simultaneous approach. We try both sequential and simultaneous approaches.

Unfortunately the initial registration is not enough to do the proper merging using surface or volume methods because some artefacts (downcasts, granules, etc.) appear in places of the overlapping surfaces (see fig. 5). However, such artefacts are not the result of faulty behaviour of the merging methods, but they depend on: noises on range images, the limited accuracy of the scanning device especially for strongly inclined faces, the angular distance from the scanner axis or simply movements of the patient during the scanning. Further we deal with such troubles (except the last one) by filtering the range images and eliminating the redundant and not reliable structures.

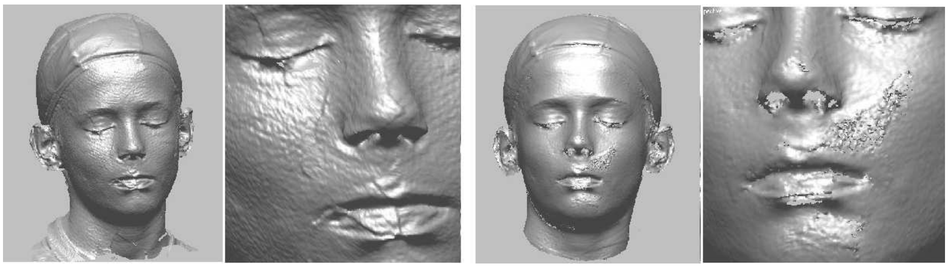
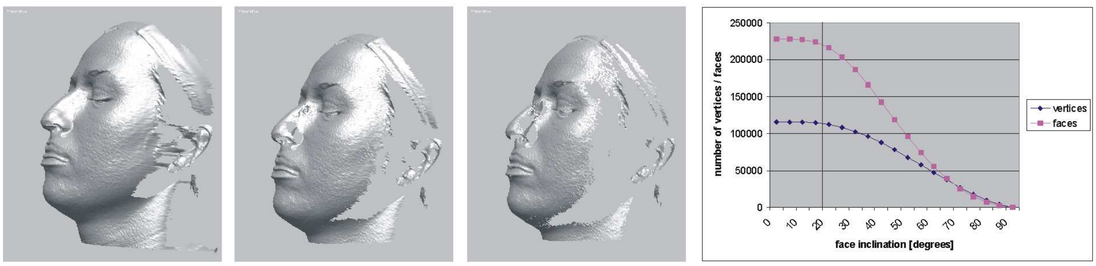


Fig. 5. Artifacts on the merged surfaces: a) b) surface merging, c) d) volume merging

6. FILTERING UNCERTAIN DATA

Two ways of filtering noisy data can be distinguished in this point: (1) removing faces inclined to the observation axis stronger than a given angle, (2) considering as doubtful faces that lay beyond an angle between two observation lines that are next on both sides to the current observation line. The second point is extended to the task of range image segmentation.



a) b) c) d)

Fig. 6. A single shell of head measurement (a) without reduction,
(b) with reduction at 20º, (c) with reduction at 30º, (d) dependence between the face inclination threshold and the number of visible faces/vertices

First we consider the inclination of surfaces with regard to the observation axis. As it was described in [1] the accuracy of scanning device is better for surfaces perpendicular to the observation axis and decreases for stronger inclined faces. Thus we use the method of reducing faces inclined stronger than a given angle. Usually we take the value of the angle as 20 degrees and as we see in fig. 6d) it is a balance between loosing too much data and considering noisy structure. Also we get rid of structures that lay below the neck as they are not necessary to create the model. In case of shell in fig. 6a) 10% of the bottom part of the structure was cut off (fig. 6b,c).

7. SEGMENTATION OF RANGE IMAGES

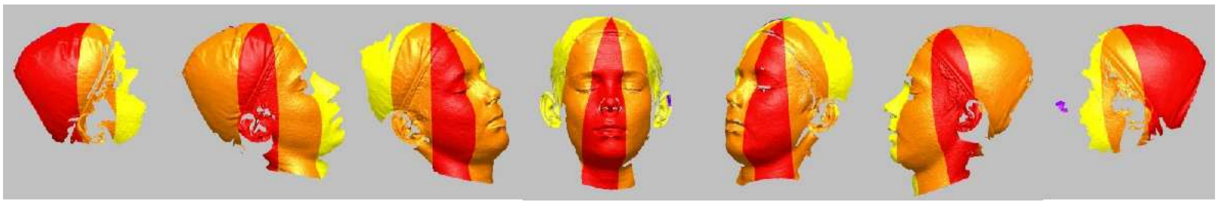


Fig. 7. Segmentation of range images regarding the reliability of surfaces

According to our method the range image can be divided into strips regarding the reliability of surfaces (fig. 7). The reliability of surfaces is proportional to the angular distance to the vertical plane containing the scanning vector. Such strategy is connected to a feature of the scanning device that the best accuracy is obtained in the middle of the scanning area [1]. The segments of the range image are selected in a discrete manner so that we distinguish strips with reliability: 100% (marked in red colour in fig. 7), 70% (orange), 50% (yellow) and 30% (violet). The most reliable strips of each shell are taken to the final global registration. Each strip is taken to the fine registration with a piece of the neighbouring structure such that the existence of the overlapping region is assured.

8. STRATEGY OF STRUCTURE MERGING

The scans are merged together after being brought into register (transformed into a common coordinate system). The determination of scanning parameters and rules for merging scans from different viewpoints are described in detail in [1]. As the final registration involved only the most reliable parts of range images at this step the structure is filled by adding the less reliable parts to places that are not covered. It is important to select the best coverage from the remaining parts and, to avoid redundancy, not cover the same area several times.

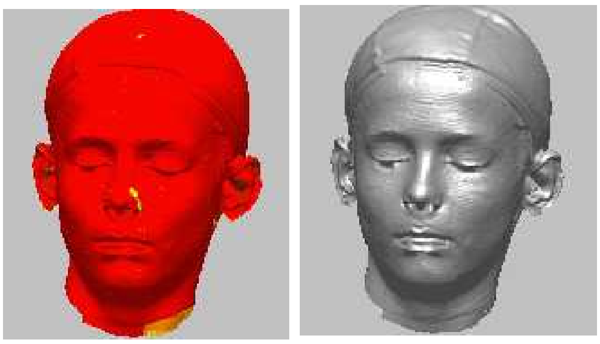


Fig. 8. The merged structure

We look through not registered doubtful parts of all shells and add these elements (vertices) that fulfil the following conditions: (1) the distance d_1 to the nearest reliable part (vertex) is more than 1 mm and (2) the distance d_2 to the line connecting the observation point and the nearest reliable part (vertex) is more than 1.2 mm. The threshold values of d_1 and d_2 appointed experimentally in the way to cover the most possible area and, on the other hand, to avoid redundancy.

The basis to the merging are the structures with the greatest relevancy value (marked in red in fig. 8), these structures are fulfilled with pieces of smaller relevancy (marked in orange, yellow in fig. 8). As the output we obtained the homogenous structure shown in fig. 8. The process has been tested on several faces.

9. CONCLUSIONS

The main advantages of the described method are: (1) automatic integration of range images facilitates the tiresome work of technician, (2) repeatability – for the same range images and the same parameters the result is the same, (3) accuracy is excellent in areas where the weight of relevancy reaches 100%, there are slight downcasts on the borders between strips and in holes filled using less relevant structures. The integration algorithm depends mainly on the quality of registration and a stable position of patients is of the great importance. Some downcasts can appear in case of movements of the patient during the examination.

Further works are planned in connection with the subject: (1) taking the average position of border structures in the merging, assuming the border area, eg. 1 cm, (2) adding the unified texture to the resultant structure so we will obtain the complete 3D photograph, (3) usage of continues – not discrete – weights to represent the relevancy of structures, (4) applying free form deformation methodology [5] to deal with unstable position of patients.

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