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Contributed Paper

Open Source Library-based 3D Face Point Cloud Generation

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ABSTRACT

Three dimensional (3D) face and body modeling is widely used in various fields such as plastic surgery, diagnosis of facial or body anomalies, 3D computer games and 3D simulation software. Since, commercial 3D face and body scanners are usually expensive, an alternative solution with lower cost is highly desirable. The objective of this study is to create 3D facial point cloud using Semi Global Image Matching method with minimum number of images utilizing a cost effective method. A non-metric Canon 600D camera with 18 megapixels resolution (3456 × 5184) and 60 mm macro lens have been used for face imaging that have been taken from a distance of 120 cm. Five faces have been modeled by the developed algorithm and scanned by David SLS-2 structured light system for accuracy assessment. Open source Cloud Compare software has been used for comparing the results of proposed method with the structured light system. The mean accuracy of five faces obtained as 90.5%. It has been observed that illumination conditions, uncontrolled movements of face or body, hair and eyebrow have negative impacts on the obtained results. The sufficiency of Semi global image matching method has been tested to create dense point cloud data from three stereo pairs for 3D facial modelling.

Keywords: 3D face modeling, photogrammetry, open source image processing library, point cloud, optic laser scanning

1. Introduction

The development of modern data collection techniques, high-resolution non-metric cameras and processing capability of computers make it easier to perform 3D object modeling. It is still a well-known and challenging research area in the field of geomatics engineering, architecture, pharmaceutical industry, plastic surgery, reconstructive medicine, human body 3D digitizing during motion, real time surgical measures, orthopedics, orthodontics and anthropometry [1-2]. Although various commercial anthropometric equipment are available in the market, they have some limitations such as cost, districted portability and, placing control points. Opposite to these systems, photogrammetric technique have more advantages due to low cost, short acquisition time and obtaining accurate results [3-4]. 3D facial modeling is also one of the popular and challenging research area for photogrammetry and computer vision researchers as depicted by Cao, et al.[5]. 3D laser scanners, Structured light systems, and hybrid systems are also used for 3D face reconstruction [6]. Different solutions have been proposed for 3D reconstruction and recognition of human face [7-9]. Nilosek and Salvaggio [10] integrated Scale Invariant Feature Transform (SIFT) algorithm [11] with Random Sample Consensus (RANSAC) [12] algorithm to eliminate unmatched points. Zhang [13] aimed to create dense point cloud by using Semi Global Matching method [9] from oblique images and Sparse Bundle Adjustment (SBA) was used to obtain exterior orientation parameters by adjustment. OpenCV [14] image processing library has been used in many image processing studies which are based on creation of 3D point clouds from multiple facial images as [15].

The main problems of 3D facial modeling are breathing and unconscious small movements of face or body. These factors can demand the decrease of photographing time and accuracy. Interest point detection and description is the most crucial step of 3D facial reconstruction [16]. Cavdaroglu [15] propose a method to detect the location of face in facial images and describe chin, eyes, nose holes and lips as interest points. Guan et al. [17] created 3D human body model from mono images. Hasler et al. [18] used multiple mono images for 3D human body modeling. Weiss et al. [19] fused Microsoft Kinect data with image silhouettes to overcome 3D human body modeling. The accuracy of the created models is very important. Stereo images are capable to acquire depth information [5]. Thus, facial models can be created for different issues. The use of non-metric cameras make this process more challenging [20].

As Wenzel et al. [21] mentioned, due to its semi-global optimization, Semi Global Matching (SGM) has some advantages. The method considers neighbouring pixels extract smooth surfaces. According to Yan et al. [22], SGM algorithm based on fusing of disparity maps from different stereo patches and it is not applicable for oblique applications due to possible loss of information. The facial images must be taken in very short time to prevent movements. In the study, SGM method has been chosen to test its efficiency for 3D facial point cloud generation using minimum amount of stereo pairs. Presented study has been performed by using non-metric camera and intended to develop an algorithm and software for 3D facial point cloud generation using open source Emgucv [23] image processing library. The Human face has been covered with six images and three stereo pairs and

3D facial point cloud has been created. Obtained results have been compared with structured light system and a commercial software which is multi-image based and uses Structure from Motion (SfM) method.

2. MATERIALS AND METHODS

Canon 600D non-metric camera, 18 MP (3456x5184), with 60 mm lens was used to obtain 3D point cloud data from multiple stereo images. The images were taken with 90% forward overlaps for five different voluntaries. These images covered front, left and right sides of their faces. Finally, the obtained point cloud data from each side was merged to form a uniform point cloud model. The obtained results were compared with commercial David SLS-2 [24] structured light system which creates point clouds with 0.06 mm sensitivity and 1280 × 800 pixel resolution.

The general overview of the study is given in Figure 1.

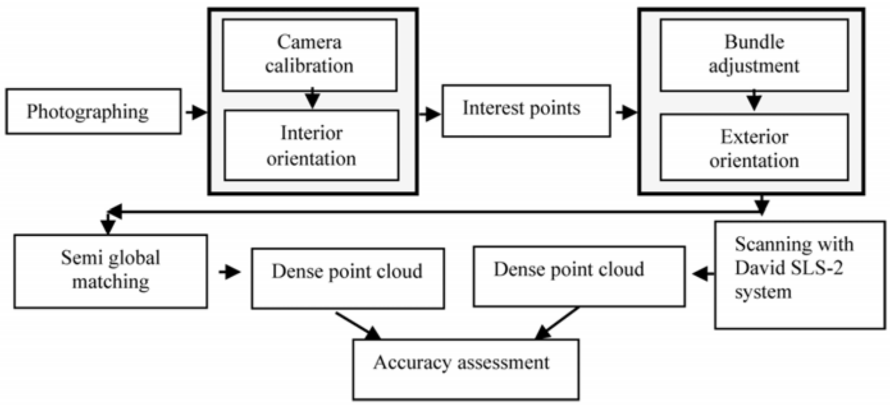


Figure 1. Flowchart of the methodology used.

Since non-metric camera was used, camera calibration was essential to calculate interior orientation parameters which are focal length, coordinates of principal point, and lens distortion parameters. "CalibrateCamera" class of Emgucv library has been used in developed camera calibration module.
The mathematical model is given below [5]:

$$sm' = A[R\,|\,t]M'$$

$$s\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_{11} r_{12} r_{13} t_1 \\ r_{21} r_{22} r_{23} t_2 \\ r_{31} r_{32} r_{33} t_3 \end{bmatrix} \quad (1)$$

where:

- (X,Y,Z) are 3D coordinates of a point
- (u,v) are coordinates of projection point in pixels
- A is a matrix of intrinsic parameters
- (cx,cy) is a principal point
- fx,fy are the focal lengths in pixel units

The re-projection error of Canon 600D camera is calculated as 0.46 pixel. Obtained calibration parameters are given in Table 1.

Table 1. Camera calibration results for Canon 600D camera.

(Pixel)			
fx	15935.36832	k1	9.572591558
		k2	0.861846327
fy	15942.4301	p1	0.000326682
		p2	-0.000227903
cx	2626.392148	k3	-6.24732846
		k4	9.624229896
cy	1519.033495	k5	1.930406748
		k6	-6.818239597
Re-projection error	0.46		

The outputs of the exterior orientation of each image are 3D coordinates of projection center (X_0, Y_0, Z_0) and three image rotations (ω, ϕ, ℵ). In this study, photogrammetric triangulation was required for dense point cloud generation. Since SIFT [11] is scale and rotation invariant interest point descriptor and (RANSAC) [12] is powerful outlier detector to eliminate mismatched points by using homographic relations between stereo pair, both algorithms have been integrated and applied to perform photogrammetric triangulation. "SiftDetector" class of Emgucv3 library (version 2.9) has been used to calculate homologous points in stereo pairs.

A 3D control point reference plate with known 3D coordinates of the points has been used for bundle adjustment and is displayed in Figure 2. The 3D coordinates of each point on the plate have been used to rescaling of created 3D facial model.

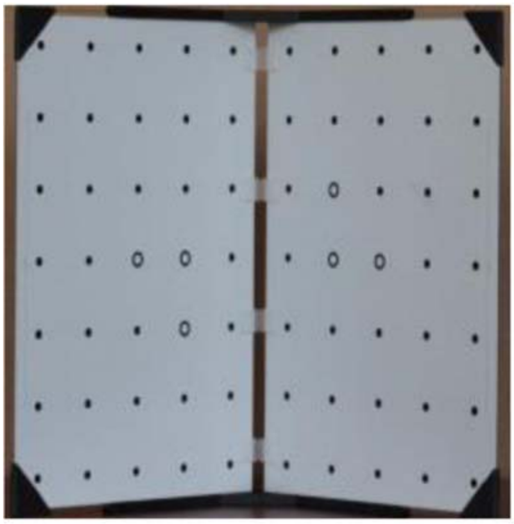


Figure 2. 3D control point area.

"BundleAdjust" method in the "LevmarqSparse" class of Emgucv [23] library has been used to realize this step. As a result, adjusted exterior parameters and 3D coordinates of the interest points have been obtained. This step was crucial to derive the dens point clouds in the next step.

The transformation from a 3D point $P_i(X, Y, Z)$ to a 2P image pixel $p_i(x, y)$ can be defined by using central projection equations [25]:

$$X = X_0 + (Z - Z_0)\frac{r_{11}(x-x_0)+r_{12}(y-y_0)-r_{13}c}{r_{31}(x-x_0)+r_{32}(y-y_0)-r_{33}c} \quad (2)$$

$$Y = Y_0 + (Z - Z_0)\frac{r_{21}(x-x_0)+r_{22}(y-y_0)-r_{23}c}{r_{31}(x-x_0)+r_{32}(y-y_0)-r_{33}c}$$

where;

x_o,y_o, : coordinates of principal point

x,y : an image point coordinates

c : camera constant

X_0, Y_0, Z_0 : 3D coordinates of projection center

X, Y, Z : 3D coordinates of an image point

r_{11},......,r_{33} : elements of rotation matrix which are function of main three image rotations (ω, ϕ, ℵ)

As it can be seen in equation (2), 3D coordinates of an image point cannot be calculated using one image. Thus, equation (2) is defined for each image. From this point, bundle adjustment calculates the unknown parameters (X_0,Y_0,Z_0, ω, φ, κ and 3D coordinates of interest points) by minimizing re-projection error between observations and predictions which is called as the sum of squares of non-linear functions that designates a real number to each member of it [26]. The Emgucv class uses Levenverg-Marquardt' algorithm. The algorithm uses an iterative technique and according to the algorithm, local minimum of multivariate function is located [27]

After accomplishing bundle adjustment and obtaining epipolar lines, Semi Global Matching (SGM) algorithm has been applied [13]. “FindFundamentalMat” class of Emgucv [23] library was used for generation of epipolar lines. This class calculates F matrix which has been given in (3).

$$x'^{T}F_{x} = 0 \quad (3)$$

Following to this, calculated interest points for two stereo images and F matrix are the inputs. “StereoRectifyUncalibrated” class was used to calculate homography matrices which are regarded as input data for “warpPerspective” [23] class to obtain rectified images as well as epipolar lines.

SGM is a pixel-based matching method which is based on mutual information and global approximating. Method consists of processing steps which are computation of matching cost, cost accumulation, computation and optimization of disparity, and refinement. The theoretical background of the method and related formulas (4-8) is given according to [9] as follows:

Mutual information (MI) can be defined from the joint entropy H of two images.

$$H_{I} = \Sigma_{p} h_{I}(I_{p}) \quad (4)$$

h_I is derived from P_I which is joint probability distribution. This is calculated by taking into consideration the corresponding parts of associated intensities.

$$h_{I}(i) = \frac{1}{n}\log(P_{I}(i) \otimes g(i)) \otimes g(i) \quad (5)$$

where;

n : number of associated pixels

⊗ : 2D Gaussian convolution

Thus, the mutual information can be defined as:

$$M_{I1,I2} = \Sigma_{p} mi_{I1,I2}(I_{1p}, I_{2p}) \quad (6)$$

$$mi_{I1,I2}(i,k) = h_{I1}(i) + h_{I2}(k) - h_{I1I2}(i,k)$$

and matching cost is;

$$C_{MI}(p,d) = -mi_{I1,fD(I2)}(I_{1p}, I_{2q}) \quad (7)$$

Disparity of a pixel can be defined as shift value which is the minimum summation of squared differences for a pixel [23] and disparity maps can be generated. Additional rules should be integrated into the system to remove occurred noise in disparity maps. SGM algorithm uses conductive decision mechanism which is energy as shown in equation (8).

$$E(D) = \Sigma_{p}(C(p,D_{p}) + \Sigma_{q \in Np} P_{1} T[|D_{p} - D_{q}| = 1] + \Sigma_{q \in Np} P_{2} T[|D_{p} - D_{q}| > 1]) \quad (8)$$

Since disparity map is created by shifting reference image and search image, the minimum and maximum values between two disparity maps should be calculated and these differences are used to define a parabola which uses minimum values. Finally, median filter if size of 3 × 3 pixels was applied to both disparity maps to reduce the impact of noise [9].

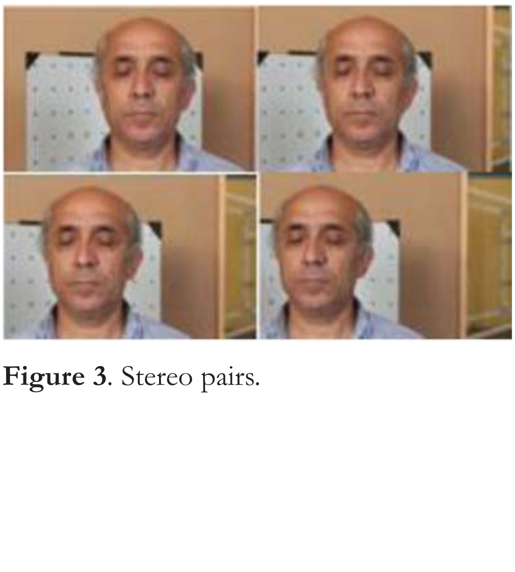


Figure 3. Stereo pairs.

Figure 4. Generated disparity map by SGM method.

In this study, “StereoSGM” [23] class of Emgucv open source library has been used. One of the used stereo image samples, created disparity maps and resulting facial point cloud is presented in Figure 3, Figure 4 and Figure 5, respectively. Obtained result point cloud data may still include noisy data which belongs to the objects around the face. Noise elimination is realized by open source Meshlab [28] software. Noisy data (Figure 6-a) and filtered point cloud data (Figure 6-b) is given in Figure 6.

(a) (b)

Figure 5. Point cloud data after filtering.

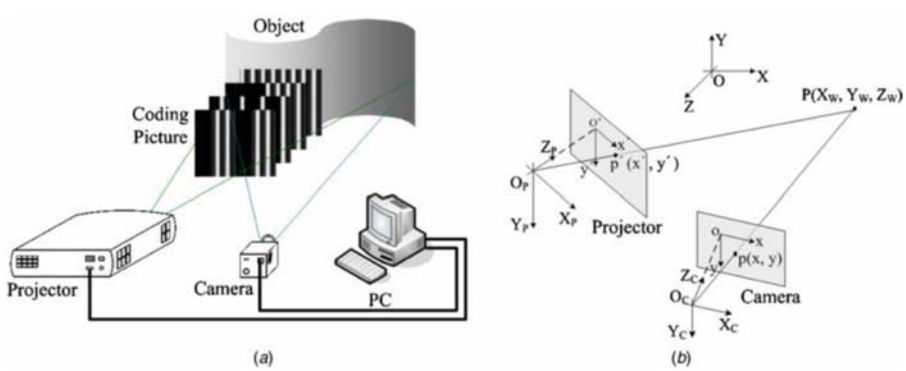


Figure 6. Structured light system [8].

3. Accuracy Assessment

In this study, David SLS-2 structured light system is used as a reference system for accuracy assessment. The faces were scanned by this system and point cloud data were obtained. Point cloud data from proposed method compared with David system. This process have been done by using open source Cloud Compare [29] software which is based on “octree” data structure an efficient way of monitoring and storing large point clouds. Besides that, differencing two large datasets can be done rapidly.

Main components of structured light systems are camera and projector system which send the known patterns to the object. Thus, 3D object coordinates are calculated from the measured deformations of the known patterns on the objects [8]. The components of the system are given in Figure 6.

Like photographing methodology, face scanning has been done in three different perspectives, and then point cloud data obtained from frontal, left and right scanning have been merged by using scanner’s own software. Scanning distance and calculated ground sample distance were 1 m and 0.27 mm, respectively. Generated 3D point cloud data from David SLS-2 is given in Figure 7-a, b. For comparison, both point cloud data which have been obtained by two different methods and coordinate system, registering was made via manually selected identic coordinates. The registered and overlapped data are given in Figure 7-c.

(a) (b) (c)

Figure 7. Scanning with David SLS-2 (a, b) and registration and overlapping (c).

Positive and negative distances were measured by software between two point cloud data generated by the proposed system and DAVID structured light system. The absolute values of distances at 0.5 mm interval have been used for analysis. The results are given in Table 2 and Figure 8. The minimum and maximum differences are measured as 0.0-0.5 /36.0-36.5 mm for face-1, 0.0-0.5/14.0-14.5 mm for face-2, 0.0-0.5/24.0-24.5 mm for face-3, 0.0-0.5/ 33.0-33.5 mm for face face-4 and 0.0-0.5/ 23.0-23.5 mm for face 5. According to Table 2, the average ratio of differences for five faces between 0.0-5.0 mm, 5.5-20.0 mm and 20.5-40 mm have been resulted as 90.50%, 9.41% and 0.01% respectively.

Table 2. Comparison results of proposed method and DAVID structured light system.

	Number of points	0.0-2.0 mm (%)	2.0-5.0 mm (%)	5.0-10.0 mm (%)	10.0-20.0 mm (%)	20.0-30.0 mm (%)	30.0-40.0 mm (%)
Face-1	1027595	62.58	31.13	5.28	0.71	0.28	0.02
Face-2	952940	75.21	21.57	3.18	0.04	0	0
Face-3	895273	78.29	18.52	2.9	0.28	0.01	0
Face-4	706279	39.15	37.67	20.33	2.73	0.11	0.01
Face-5	646184	55.06	33.3	10.05	1.55	0.04	0
Average		62.058	28.438	8.348	1.062	0.088	0.007
Sum		90.50		9.41		0.09	

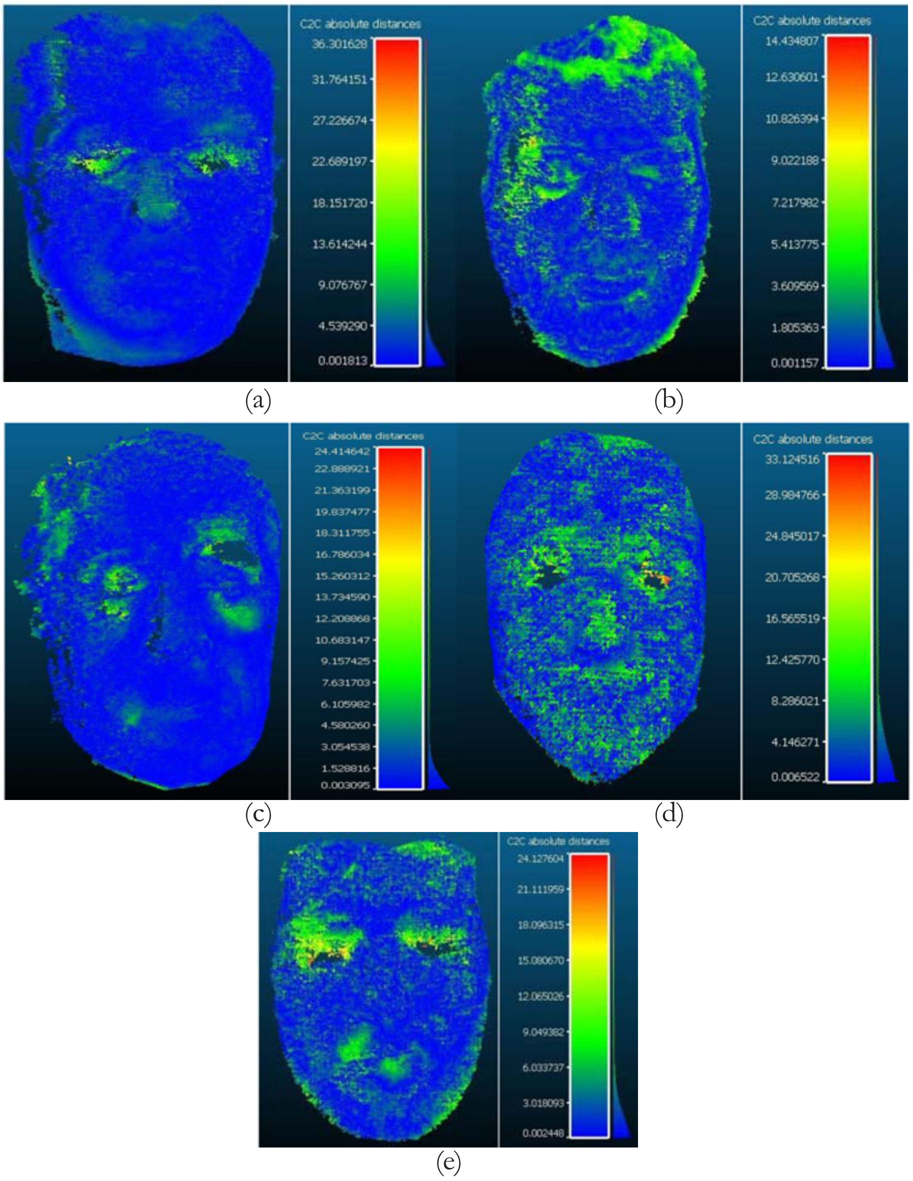


Figure 8. Distance maps between proposed method and DAVID scanning system.

The results of the proposed method has been compared with the results of another commercial software Pix4d which is based on multi-image approach and SfM method [30]. Same as the developed method, 6 images of Face-3 given in Table 2, were used to create 3D facial point cloud from commercial software. Thus, the performance of the developed system has been tested with multi-image based method by using open source Cloud Compare software. The created 3D facial point cloud and comparison results are given in Table 3 and Figure 9, 10 respectively.

Table 3. Comparison results of multi-image based method with DAVID structured light system and proposed method.

Face-3	Number of points	0.0-0.5 mm (%)	0.5-1.0 mm (%)	1.0-1.5 mm (%)	1.5-2.0 mm (%)	2.0-3.0 mm (%)	3.0-5.0 mm (%)	> 5.0 mm (%)
Multi-image-DAVID	923282	37.63	20.77	10.33	7.92	10.67	10.25	2.43
Proposed method-DAVID	895273	28.34	23.37	16.42	10.17	10.60	7.91	3.19
Multi-image-proposed method	923282/ 895273	38.95	37.29	13.27	7.15	7.93	4.99	0.42

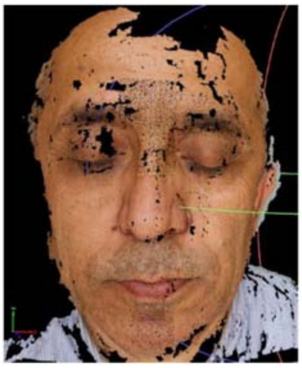
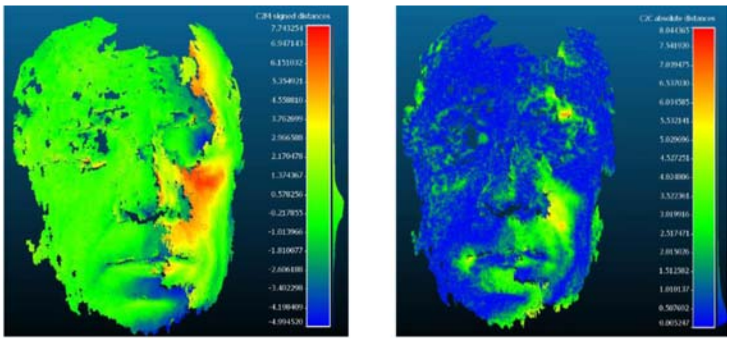


Figure 9. Created 3D facial point cloud using multi-image based method.



(a) Distance map between multi-image based method and DAVID system

(b) Distance map between multi-image based and proposed method

Figure 10. Distance maps between proposed and other two methods.

Figure 10-a, shows the difference map between multi-image based method and DAVID system. Figure 10-b shows the difference map between multi-image based and proposed method. It is obviously from Figure 10-a, b and Table 3 that the differences are slightly similar between multi-imaged based and proposed method.

4. RESULTS AND DISCUSSION

In the study, 3D point cloud data of faces was produced using multiple stereo images. To obtain 3D face model, five different face photographs were taken with Canon 600D non-metric cameras (18 MP, 3456 × 5184, with 60 mm lens). A total 4,478,976 points were generated for each face. The proposed method was suitable to create 3D point for each conjugated pixel per stereo pair. However, it was observed that processing of large data is time-consuming and in some cases, unavailable for standard laptops. Therefore, point cloud data generation was arranged to create one single point from each two pixels in vertical and horizontal axes to decrease processing time.

The algorithm was coded in C# Visual Studio 2012 Express Edition platform. 2.9 and 3.0 alpha versions of Emgucv open source image processing library was used as basic infrastructure of developed prototype software. The reason of using two versions of Emgucv library is that SIFT algorithm works with version of 2.9 and SGM algorithm works with version of 3.0 alpha. In the developed software, integration of derived inputs and outputs from both versions were accomplished.

Commercial David SLS-2 structured light system was used for accuracy assessment. Differences between point cloud data from both systems were calculated using open source Cloud Compare software. Point cloud data which have been generated from two different methods was registered prior to calculation of the differences. The registration errors have been calculated for all five faces as 1.49 mm, 1.27 mm, 1.43 mm, 3.29 mm and 2.04 mm, respectively. It can be stated that root mean square errors could be smaller. However, this was not the case due to working with live objects. Scanning time with DAVID system and photographing took approximately 10-15sc, 10sc respectively. These steps were done consecutively for accuracy assessment issue. Therefore, scanning results were affected because of the unavoidable small movements like breathing, time difference between two different measurements. To overcome this issue, either photographing or scanning procedures were repeated again and again to put the voluntaries in stable position as much as possible. From this point of view, the second question can come up as why accuracy assessment has not been done by using stable objects? For this purpose, statues may have been used. In this case, due to homogeneity and smoothness of the object, image matching results were unsatisfying. Instead, photogrammetric stereo processing systems can be used in such cases.

After the registering process, the differences between DAVID system and the proposed method were calculated at 0.5 mm interval. As a result, 93.71%, 5.99% and 0.3% of the differences were in 0.0-5.0 mm, 5.5-20.0 mm and 25.5-40.0 mm ranges, respectively for face-1. The calculated differences in same ranges were 96.78%, 3.22%, 0% for face-2, 96.81%, 3.18%, 0.01% for face-3, 76.82%, 23.06%, 0.12% for face-4 and 88.36%, 11, 6%, 0.04% for face-5. The ratio of points in 0.0-5.0 mm range of face-4 and face-5 were less than other faces because of illumination changes as these images were taken in different illumination conditions to see its effects on the algorithm.

Since the effects of illumination change, movements because of breathing, hairy areas, etc. were not eliminated from the calculated differences, the accuracy assessment results have been obtained including these effects and registration accuracy. It has been observed that calculated differences were higher in hairy areas like eyebrows, beard, mustache and eyelash. For instance, as shown in Figure 11, because of movement of eyebrow the difference has been measured as 1.20 mm and in the beard area as 1.08 mm. In contrast to these differences, in stable areas of the face manually measured differences were 0.28 mm.

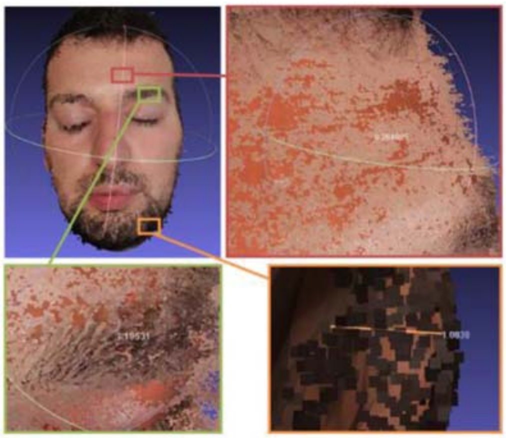


Figure 11. The impact on the accuracy of the bearded area.

In the presented study, macro objective was used. The photographing distance has been taken as 120 cm and photographic base has been calculated as 5 cm. Due to physical size of the used cameras, it was not possible to fix them in 5 cm base with tripod. Therefore, the photos were taken by free hand only with one camera. Because of this restriction, unwanted movement artifacts were indispensable. This reality can be counted as one of the error resources. However, some errors in the overlapping areas of the multiple stereo pairs have been removed by merging of the produced point clouds which have been generated from frontal, left and right stereo images.

It has been observed that SIFT and SGM algorithms are affected hardy from small movements. Especially illumination conditions are very important for SIFT algorithm. The photographs have to be taken under homogenous light because flares in images can cause lack of matching and holes in produced point cloud data. It has been observed that RANSAC algorithm is highly capable to eliminate unmatched points.

Better understand the reliability of the proposed method; the achieved results were compared with multi-image based system and DAVID system. According to Table 3, the calculated differences between multi-image based method and DAVID system are 76.65 % , 20.92 % , 2.43% in 0.0-2.0 mm , 2.0-3.0 mm and greater than 5mm interval respectively. As it can be seen in Table 2, the same comparison ratios between proposed method and DAVID system were calculated as 78.30%, 18.51% and 3.19% which are very close to each other. When the proposed and multi-image based methods are compared, differences are calculated as 86.66 %, 12.92% and 0.42% for the same intervals. The results show that proposed method and multi-image based method creates similar results from 6 images.

In the presented study, low-cost system for 3D face point cloud generation was presented. Proposed system is capable for industrial applications after additional electronic improvements. The studies on enabling the algorithm to make more efficient and independent from illumination conditions and small moving artifacts are in progress.

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