Digital Smile Design: an engineering-based point of view

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***Abstract*—Technical report for a Biometric project regarding the digital smile design & dental visual reconstruction which allow the user to insert a facial image and detect both its facial and dental mid-lines then based on facial landmark detection it can make some major changes to the image to reflect how would it look if done, the major changes the program can do are Detecting and changing, if needed, the color of the teeth, Detecting the Diastema, Fixing the diastema by applying a dental template, and detecting the gum, The paper contains all the information needed in this project as also the tools, functions, and data we used.**

***Index Terms*— Aesthetic, Biomedical Engineering, Biometrics, Digital Smile Design, Facial reconstruction.**

I. Introduction

Aesthetic smile design process depends on a conception of perception, so we have to create a computerized virtual visualization for the outcome of this process, as it is "an irreversible restorative dental procedure" *(Personalized Digital Smile Design for Predictable, 2016)* , and as our research reached in the DSD we found a space for enhancement as part of the updating evolution of DSD, *(Jafri, (2020))*, also as the world is heading hard towards Automation, we saw how important and valuable is the automation in such a complicated way, the automation which would start from the image used to the final product of the DSD, so we hope that our work in this field would add to the process, and so we will explain each step in the process of creating this virtual image.

II. STEPS OF THE DSD

In this process we have gone through various ways and technologies, but the following is the last and most suitable road map we have reached starting with, Facial landmarks, then Facial mid-line, Teeth segmentation, Teeth mid-line, Color detection, Gum detection, Diastema detection, and finally applying the dental template.

The work on this project has took various turns, as we worked first on a 77-point face detection API, but we faced some troubles in implementing some features by this API, then we considered Google vision API, and it worked fine foe the most part of the features, but it requires license and should be renewed, so finally we considered face-mesh which can provide us with all the points needed and also the documentation.

A. Facial Land marks

The program is coded to open the Image selected and based on the face mesh Application Programming Interface (API), It locates the coordinates of all the facial landmarks as illustrated in Figure1, and as each point of the face is located in a 2D array in terms of X and Y, then based on these coordinates we can do different operations "i.e. Facial mid-line and detecting mouth-edges"

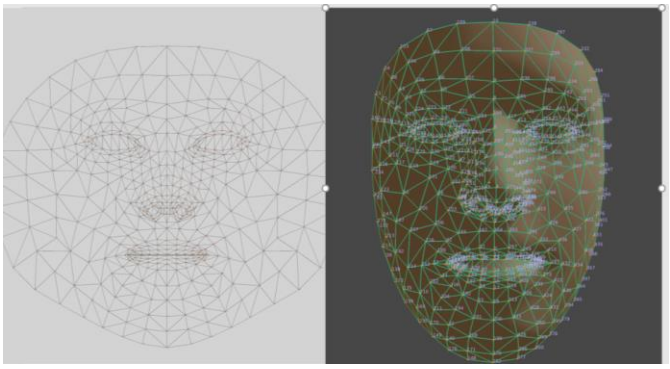

Figure 1.Face-mesh Points

B. Facial Mid-line detection

In this part the points and coordinates collected from the face-mesh can be used to determine the mid face points which when connected, it forms the mid-line, the used points are: the middle of the forehead, the nose tip, the mid upper lip and the jaw mid-point as pointes number 10,19,0,152 respectively, and based on these points the mid-line is drawn in a relative motion to the face (e.g. if the image of the face is inclined the mid-line will be inclined by the same angle as illustrated in figure 2), and after this we can cut the mount as it is the Region of Interest (RoI) in the Digital Smile Design (DSD) process.

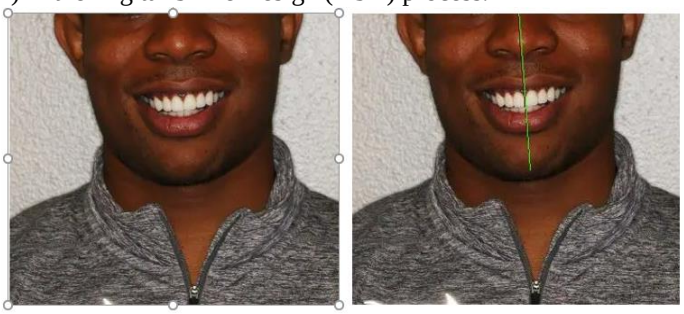

Figure 2: Inclined facial mid-line

C. Mouth Cutting and Teeth Discoloration

To start working on the teeth, we had to narrow down the ROI, so it is easier to determine and change the defects, to do so we used both the API coordinates and the color filter to cut the mouth by determining the main mouth coordinates in terms of X and Y, we used the points 78, 191, 80, 81, 82, 13, 312, 311, 310, 415, 308, 324, 318, 402, 317, 14, 87, 178, 88, 95, which starts from the left edge of the lip and going through all the points inside the two lips, so it only take the RoI, and also by calculating the average of the teeth color, so it is easier to eliminate the below-average components, which are skin and gum component, then it leaves us with only the teeth as illustrated in figure 3a and figure 3b.

Figure 3a:the cropped teeth *Figure3b: the full face*

Once the teeth are separated from the rest of the image, now we can make the desired operations (e.g. Bleaching), but the main obstacle was changing the color of the teeth without erasing the edges, so edge detection was needed, then we used canny edge detection and excluded the edges from the bleaching process, and the result is shown in figure4.

Figure 4:Before and After bleaching

And the options in bleaching colors used are:
(234 ,223 ,195), (255 ,255 ,255), (231 ,221 ,197)
(228 ,211 ,169) in *RGB*.

D. Dental mid-line

The method used to draw the Dental mid-line, was by using the facial mid-line and the cropped image of the mouth and by determining the whitest horizontal line (high pixel value), we draw a line, and starting from the intersection between them, *the facial mid-line and the horizontal line*, we detect the nearest vertical edge and this would be the Dental mid-line, as shown in figure5,

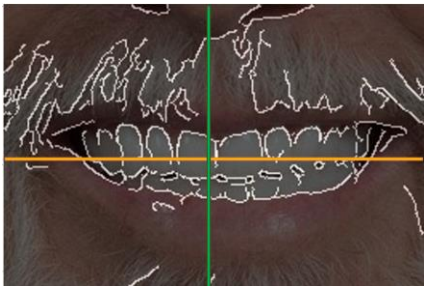

Figure 5: Dental mid-line

The used Gaussian blur was to smooth the image with a kernel size of (5 5) and the upper and lower thresholds was 100,200 respectively.

E. Gum Detection

To detect the gum, the program runs over all the pixels in the cropped image of the mouth and see the value of the pixels if it is within the average range of the gum color then we count it within the gum, after counting and determining the gummy pixels we can make a mask of their presence, as in figure6, and based on that we can determine if this case has a gummy teeth or not

Figure 6: the gum mask

F. The Gap Detection "Diastema"

For the gap detection, we focused on the incisors so we cropped this part of the mouth from points 82, 13, 312, 317, 14, 87 starting from the edge of the maxillary right lateral incisor to the edge of the maxillary left lateral incisor with the same height of the cropped images, then we go bit by bit on it to calculate the mean and the standard deviation of all the pixels, after that we can calculate the threshold level and then count the number of pixels below the threshold and based on the ratio calculated, if

$$(Black\ Pixels\ /\ Total\ pixels) > 0.05$$

Then we can say that there is a Diastema.

G. Applying The Template

The final product of this long and complicated process is a perfectly matching smile, and as we referred in the introduction it is a process that depends on a conception of perception, so even if the output is automatically matching all the requirements needed, it may not be accepted by the user, therefore we made it semi-automated as it will be placed automatically on the image, but it can be edit after to match the desired output.

The template is placed initially by determining the matching outline of the two maxillary first premolar as the template itself is between these two as in figure 7, then we crop the image by these boundaries to resize the template to fit the actual image, by matching the middle of the image with the upper lip mid-line.

Figure 7: Teeth templates

And to ensure that it fits the user, we made it resizable as you can increase or decrease its size from the Graphical User Interface “GUI”, and also movable if wanted, and the result was as in figure\8.

Figure 8: Before and After Applying the template

III. Results and Discussion

As we used the program on the available data set, linked in the references, we measured the accuracy of the features we made and it was as illustrated in table 1

Feature	Dataset	Successful	Rate
Facial Land marks	50	50	100%
Mid-line	50	46	92%
Mouth Cutting and Teeth Discoloration Detection	50	42	84%
Gum Detection	50	33	66%
The Gap Detection	50	23	46%

Table 1: The results

And we can say that the results mean that the application of the Facial land marks was correct in most cases, but the images with very poor resolution or has be filtered digitally may not get detected.
For the application of the mid-lines based on the face-mesh was successful in most case except the images with cropped parts of the face, so it is recommended to use a full face image.
The mouth Cutting and discoloration detection has 84% rate, and the reason for the undetected or misdetection of it was the different lightning which changes the threshold needed to detect the discoloration, and the recommended setup for the image is to be medium or equally distributed all over the image and using no filters.
And the color template applying is solved by making the user choose the color he wants from the GUI.
The same recommendations of the Teeth Discoloration Detection are applied for both The gum and the Gap detection as high lightning increase the pixel value detected which may lead to wrong diagnosis.
Finally Applying the dental template is suitable for most of all cases, and to solve the rest we made both removable and resizable to match all the desired changes

IV. Conclusion

To conclude, we can say the process of the DSD has a lot of areas that most of it can be fully automated, but as we went deep into it we saw that it is really a matter of perception, the user mostly does not want the perfect output, he wants the perfect match, so there will be always edits, therefore we strongly support making it editable and left for the user to decide, and we search more in normalizing the defects of lightning that faced us in the detection process to get a better result.

V. References

Jafri, Z. A. ((2020)). Digital Smile Design-An innovative tool in aesthetic dentistry. *Journal of oral biology and craniofacial research*, 10(2), 194–198.

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