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Image Morphing Techniques: A Review

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Abstract

Nowadays image morphing has become one of the important techniques in applications that require a graphical representation of objects. Morphing tools have become very well known among users who work on multimedia applications such as art effects, virtual games, photo morphing, and social media, in addition to scientific and academic fields. There are many algorithms to apply morphing operations, including the basic and improved techniques, which share some essential stages, but vary in the algorithm details and the produced image qualities. Morphing techniques, in general, are based on image features and changing them through a warping process to produce another image or mixing two images to produce a new combined image. This paper provides an overview of different morphing techniques explaining how they work and discuss their features in some terms such as the morph visual quality, technical efficiency, and complexity, which can assist the researcher in the image morphing field to compare and identify morphing techniques that suit their working area.

Keywords: Metamorphoses, Image transformation, Warp generation, Feature specification, image blending.

1. Introduction

Image morphing has become one of the most popular techniques for image transformation that is used in many fields, especially on multimedia and visual effects including image retransforming and photo editing tools, this technique is also efficient for graphics, animation, and game design that attract users whether for computer graphics or mobile applications. Morphing technique for image processing which is also known as "metamorphosis", has proven to be a powerful tool for visual effects [1] [2]. Morphing operation is defined as, a process that changes one image into another through a seamless transition [3]. Appling image metamorphic on two images starts first with the animator to establish the correspondence between the pairs of features primitive, such as curves, mesh nodes, line segments, and points [1] [2].

Morphing operations include image processing approaches such as warping and cross-dissolving. [4]. Image Morphing technique is based on mixing the pixels of two images to merge a picture of two persons (for example), the first image (source) will be transformed into the target image by selecting sets of points or features of the images, so the result will also be an image but with different features and characteristics or a new image. Where warping determines how pixels from one image correlate with corresponding pixels from the other image [4]. The corresponding feature sets are then used to produce a mapping function, which is the (warp function) [3]. The morphing algorithm's performance depends on selecting a point from the images to be mixed according to some mathematical equations related to the applied algorithm. So mathematical morphology is defined as "a field that studies the topological and structural properties of objects based on their images" [5]. During performing warping and morphing operations the steps of transforming the original image into another shape can be presented as a sequence of figures (animation) where the user can see the process of the transformation operation.

Morphing techniques can be applied to a complete image or by selecting some points or apart from a picture, selecting human faces from a picture, to apply a morphing operation became one of the important fields in image manipulation that is called (face morphing)**,** which aims to create a new face image that resembles the biometric information of two or more face images [6]. This technique became an important tool for real-time facial animation and 3D video games [7]. Moreover, image-morphing techniques can be used to reduce memory consumption and preserve the perceptual quality of animations as in [8]. Although image morphing technique is very famous in entertainment applications, on the other side it can be used to produce fake images which cause a security issue, especially for face recognition systems thus, face morphing attacks have received great interest from the biometric community [9], which become an important topic nowadays, that aims to study morphing techniques and detect morphing attack as in [10] [11] such studies are very important recently due to the rapid development along with quality improvement of morphing algorithms that make it difficult to distinguish between origin and the transformed (manipulated) image.

Due to the importance of morphing algorithms' effectuation in many applications. This research aims to present an overview of classic and modified techniques related to morphing algorithms, which will be listed in section three.

2. Morphing algorithms principle

The principle of Image morphing is transforming an image into another image. The transforming process is widely used in motion image applications and movies that need special effects. Where the work on image transformation started in the early 1980s [12]. The operation can be linear which means transforming linear images or morphing an image by segmenting the image into lines and then transforming them to create the result according to the target image [13].

Prior to the development of morphing techniques, image transformation was commonly carried out by cross-dissolve techniques e.g., linear interpolation to fade from one image to another [1] [2]. That's wherever one image is light out and an alternative image is light in, therefor such a technique wasn't effective in signifying the metamorphosis [14]. These approaches are generally invariant to the semantics of the underlying object making them vulnerable to artifacts such as "ghosting" and implausible intermediates [15]. Therefore, morphing operations were developed to achieve fluid transformation by using warping to preserve geometric alignment by the cross-dissolve operation [1] [2].

Image warping is defined as "the process of digitally manipulating an image such that any shapes portrayed in the image have been significantly distorted" [16]. So, morphing techniques became a combination of two operations, warping i.e. (shape geometric) and cross dissolve i.e. (color photometric) [13]. Where the warp is specified by a mapping between lines in the first and second images [16]. Warping techniques are very important to reform the images, using inefficient warping operations or pixel mapping will produce misfit morphed images. Although, there are many morphing techniques the difference in these techniques is mainly in how to apply warping [17]. Another important step in the morphing operation is selecting lines or points ...etc. of the image (features). Feature specification is the most tedious feature of morph operation [1].

In following figure 1, illustrates morphing and cross-dissolving images between origin images (a) and (b), where figure (c) shows the intermediate result of the cross-dissolve operation on images (a) and (b), while image (d) in the figure shows a frame of morphing sequence [5].

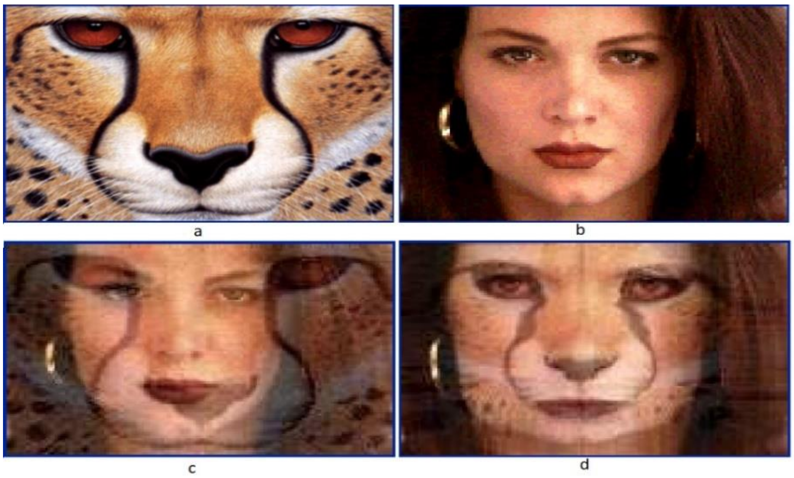

Figure 1. Example of morphing operation of origin images (a and b), the result of the cross-dissolve operation in c, and a frame of the morphed image in d [5].

3. Morphing and warping techniques

Pioneering morphing algorithms combine corresponding driven bi-directional warping using blend operations to generate a sequence of images despite the entities in play [15]. Pixel interpolation is a very important step to generate the morphed image. This process can be applied to the entire two images, or by selecting some features from them, the morphing process starts with the first image then blend it into the second image and fades. Morphing techniques are in continuous development to produce a good result, the techniques differ in the details but still share the basic steps, in general, three main processes are required for morphing operation: feature specification, warp generation, and transition control [4].

This section reviews 9 warping and morphing techniques, including the basic methods which are: (Cross-Dissolving method, mesh warping, field morphing, triangulation-based morphing, energy minimization, multilevel free-form deformation, and work minimization, besides methods for 3D faces morphing and morphing using structural similarity). The review shows the progress in image morphing techniques with their specifications and modification. The following subsections discuss these techniques.

3.1 Cross-Dissolving Method

Years ago, when morphing was not developed yet, image transformation operation was achieved with the help of the cross-dissolve technique [3]. This operator makes a transformation on two images without considering the transition between the different objects contained in the image [5]. The concept of cross-dissolving operation is that an image will fade to another image using linear interpolation [4]. In this process, the color of each pixel is interrelated over time from the first image value to the second image's corresponding value [16]. An example of a cross-dissolve operation on two pictures (f and g), is crossing dissolve picture (f) to (g) means taking a sequence of images [5].

The cross-dissolve method can be considered a primitive method of morphing operation, and suffer from some visual artifact that appears on the resulting morphed image. One of this method’s problems is that the image at halfway through the morphing process, maybe seemed to be a “ghost” effect or a (gloomy zigzag) image [3] [13], also the outcomes of the crossing-dissolve approach are poor, having a double-exposure effect apparent in misaligned regions [2] [3]. Besides when using face image morphing the double exposure result within the eyes and mouth areas is seen and the morph doesn't look natural [14]. In order to avoid these issues, warping is used to align the two images before cross-dissolving [12]. A study presented in [17] proved that the result of a morphed image is very bad in the case of applying only cross-dissolving operations without warping, the reason for that is, the input and the destination pictures are not aligning. Because the warping algorithm keeps the geometric alignment of the areas by the cross-dissolving operation, so the morph operation will achieve a fluid transformation between the destination and the source image [3]. Figure 2, presents the progress of cross dissolving operation on five frames, it is clear that in the middle step, there is double-exposure effect also appears, that the input images will contribute equally to the output [1] [2]. From the figure, it can be noticed Image overlapping start from the second frame, with blurring and ghost artifact, especially on the eyes and the hair.

Figure 2. Cross-dissolve sequence over five frames [1].

3.2 Mesh Warping

Mesh warping algorithm is one of the most interesting approaches for morphing operation, it is considered one of the basic and traditional techniques. The technique pioneered at Industrial Light & Magic ILM) by Douglas Smythe which is used in a movie named *Willow* in 1988 and later used successfully in many subsequent motion pictures [1] [2]. The mesh warping concept works by breaking pictures into little areas and mapping the pixel from the source to the objective picture. So, no specter lines appear in the picture [18]. This warping depends on how the mesh is implemented, such as using a rectangular grid of mesh. To apply it, the edge must coincide to the features of the image without self-intersection between the grids [19]. Figure 3, present an explained where the mesh morphing algorithm is applied on a source and destination image at the left and right of the figure, the middle image represents a metamorphosis (morph) between the two faces at the left and right of the figure [12].

Figure 3. Example of mesh morphing [12].

G.Wolberg described in detail the two-pass mesh warping algorithm in [1] [2]. This is summed up as follows: to apply the mesh algorithm on two images (source and target) their coordinates of control points, must be specified at the source and target image, to associate the source mesh (Ms) with the target mesh (MT), which are used to define a spatial transformation that maps all points in the source and target image. [1][2]. Using mesh tables for the source picture is mapped to a mesh table for the destination picture, then for each mesh, a calculation is applied, that could be easily computed [20].

Although mesh warping is one of the predominant approaches, it suffers from some problems including ghosting [21]. besides when the grid size increases the computations will increase also [12].

Therefore, many researchers modified traditional morphing algorithms to provide efficient results. N. Fish et al., presented a new approach for the morphing effect that aims to leverage the power of deep neural networks to learn a shape prior to fitting a given source dataset [15]. Deepalakshmi in [14] developed an algorithm where polygon meshes square deformation technique is employed, mesh deformation breaks pictures into a little region and maps pixel to pixel from supply to focus on the image, according to the author, the technique produced the best visual result due to implement mesh-based image morphing [14].

Another issue in this approach is the control points, which are represented by the line intersection of the grid, may not be enough in certain regions if needed [21]. Thus, the same resource proposed improvement of mesh morphing to overcome the problem of control point misalignment that causes the ghosting effect, by indicating the coordinates of control points [21].

3.3 Field Morphing

The field morph approach was first presented by Beier and Neely [22]. This technique is proposed to improve mesh warping performance, where image features are considered instead of depending on mesh nodes. The proposed technique leverage user-defined line segments for the establishment of the corresponding feature point that is used to distort each endpoint toward the other [15]. The pairs of lines characterize mapping from one picture to the next where one line can characterize the connection to the goal picture [18] then warping operation can be applied according to these lines that represent for example the nose or mouth in the image. According to Beier and Neely's paper, the simplest scenario of the algorithm is that the animator must specify the control points of the image and draw lines on it. Then the animator must take the given points and place them at the correct locations. While the points that are accidentally left, or points that the animator could not find an associating feature will still be used by the warping algorithm [22]. The strategy of this approach depends on pixel distance concerning the lines that are drawn on the origin and the destination [12]. Where the displacement of a point in the original image is a weighted sum of maps resulting from each line pair, with the weights attributed to distance and line length [1]. Figure 4, presents an example of drawing lines over a face for a field morphing algorithm with the resulting image as can be noticed the result is very good and the two images morphed without a ghost or blurring effect [22].

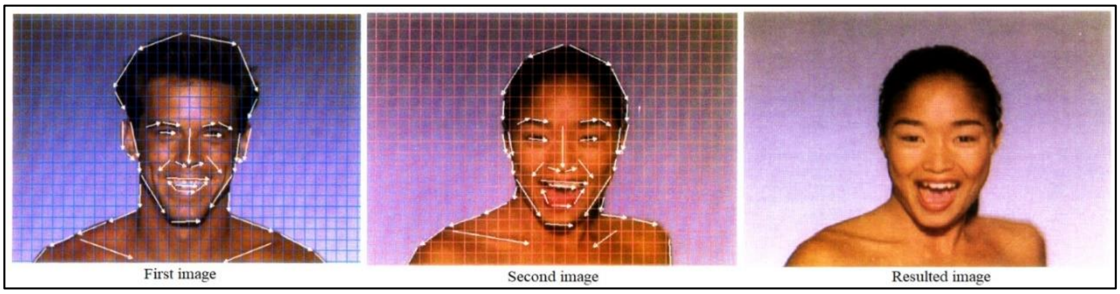

Figure 4. Drawing lines over a face for field morphing algorithm [22].

Feature morphing techniques produce good results for orientation images [17]. Although this morphing algorithm produces good results, its disadvantage was that all the controls are given to the animator. Thus, the technique was modified later, the future scope of this technique is automatic feature selection for morphing [12]. Beier's algorithm was modified to speed it up, by Hussain Karam et al. presented in [23] proposed a modified feature-based by applying an endpoints algorithm which modified Beier's method for lines features transformation, where just feature line endpoints are morphed and the remained points are transformed according to these endpoints [3]. Jya-Kai Chang et al. in [24] used field morphing for face morphing to develop a simple system for the user, that can synthesize facial features, then ideally create a sequence of fluid transformations between two pictures, the method enables users to draw features directly and contour lines on the source and destination image. Many animators used both mesh and field morphing algorithms to create a good visual effect [16] [24]. Jya-Kai Chang et el. compared this method with mesh morphing and concluded that field morphing spends most of the time creating more feature lines for warping, but its performance is better than mesh morphing [24]. Another study in [25]. Presented the limitation of mesh morphing is that quality result is only good if the source and the target image have a similar shape, while field morphing is simple but tedious. It is obvious that merging morphing techniques can improve their performance as in [26] proposed hybrid image morphing method by applying feature-based and mesh warping algorithms, combined with cross-dissolving methods. the author explained that the proposed algorithm presented an efficient morphed outcome by finding control of the grid and mapping the related pixels of the source image to the goal image.

3.4 Triangle Mesh Warping

Selecting the correct colors, shape, features, shape points, and information of an image is very important to create a perfect morphing operation. Therefore, the work continues to improve warping operation with efficient point selection. Thus, a development on mesh warping is proposed by dividing the image into groups of triangular, Delaunay triangulation is a popular method for optimum triangulation of a set of points [20]. Delaunay's triangulation feature maximizes the minimum inner angle of all triangles in order to avoid thin triangles [17] [21] [27]. A technique proposed by Ruppert [28] used a successive refinement of the Delaunay triangulation that uses a uniform mesh (all triangles with the same size). Ruppert refinement algorithm is for bounded aspect ratio triangulation of planar, producing mesh with fewer triangles and with varying sizes, where the intersection of two triangles can be a common edge, empty set, or vertex. While the mesh generation technique must guarantee shape measuring, where the mesh is size optimal within a specific constant factor [28]. Figure 5, shows an example of a triangle-based mesh morphing method by using 6 lines selected by the animator.

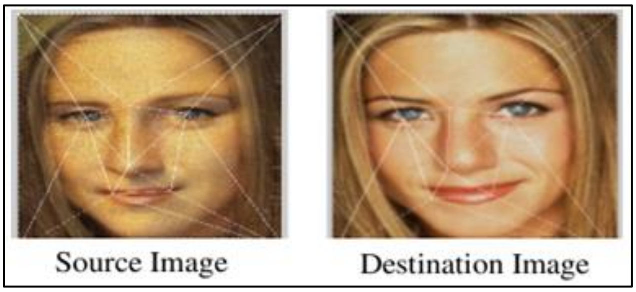

Figure 5. Triangulation morphing with 6 feature points [17].

Using triangles is still interesting to improve point selection Sofie et. El [29] proposed an algorithm based on triangulation to generate new geometric data objects that partition the given objects, the aim of this algorithm is independent of the particular choice of the coordinate system. Triangulation-based warping algorithm is automatic it can produce good effects on the same orientation images [17]. A common problem of image warping using triangulation-based methods is that foldover may occur easily [17][21][27]. Which degrades the resulting image quality. Fold over term describes how the overlapping deformations process occurs, this means that many nonadjacent in the source image are mapped to the same pixel of the output image [27]. This problem occurs when the corner point orientation changes to any triangles, that is the triangle is flipped over by the deformation [17].

A comparison study in [17] concludes that morphing algorithms based on triangulation implementation are complex and take a significant amount of time if compared with morphing using the feature-based algorithm. However, the technique inspired many researchers in reference [30] to use automatically specified feature selection for face morphing where feature specification is applied by using a neural network, edge detection, and medium filter. Then warping is applied by using triangle-based mesh morphing. This approach reduces the time of computation since the control points needed for image morphing are very less [3].

3.5 Energy minimization

The previously mentioned methods have some weaknesses to generate morph or warp images (flood or ghost artifacts) where the result might be distorted, therefor Energy minimization techniques were proposed to provide full image warping, presented by Lee et al. [31]. To generating one to one warp function from a set of point pairs overlaid on two images by using tow dimensional deformation that efficiently generates (C^1-) continuous with one-to-one deformations of positional constraints, according to the authors, the method does not restrict a feature set to have any structure such as mesh method, hence allows greater freedom in warping design. The freedom together with good warps makes it possible to obtain desired in-between images very effectively [31]. This technique produces features that meet one-to-one correspondence the energy clause is sequential and the warping function is calculated to minimize the sum of it [3]. This technique produces a natural warp since it is based on physically meaningful energy terms. However, the performance of this method is hampered by its high computational cost [1] [2].

3.6 Multilevel free-form deformation

Since each of the previous methods has some drawbacks. A new warp generation was presented by Lee et al. in [32]. Which is easier and faster than the related energy minimization approach [1] [16] [31]. Lee et al proposed multilevel free-form deformations (MFFD) to achieve C^2- continuous and one-to-one warps among feature point pairs. The authors adopt a computer vision technique named snakes to reduce the burden of feature specification. A Snake: is an energy-minimizing spline guided by external constraint forces and influenced by image forces that pull it toward features such as lines and edges [33]. This method was adopted since generating snakes from polylines and curves, then the positions of features can be derived more effectively. The proposed MFFD derives warps as an extension of the free-form deformation (FFD) method that aims to deform surface geometric models in a free-form manner proposed by Sederberg et al. in [34]. FFD recomputes control points' positions depending on the surface point(s) movement to ensure that the resulting surface passes throw newly positioned points [35]. Lee et al showed that the proposed MFFD technique aims to reduce image morphing feature specification, the problem of warp generation, besides surface generation for issues with transition control problems, that appeared in the previous morphing techniques and that the generated warps provide visually pleasing image distortion, as can be seen in figure 6, One of the MFFD morphing benefits on feature specification is that it is more expensive and less cumbersome [3].

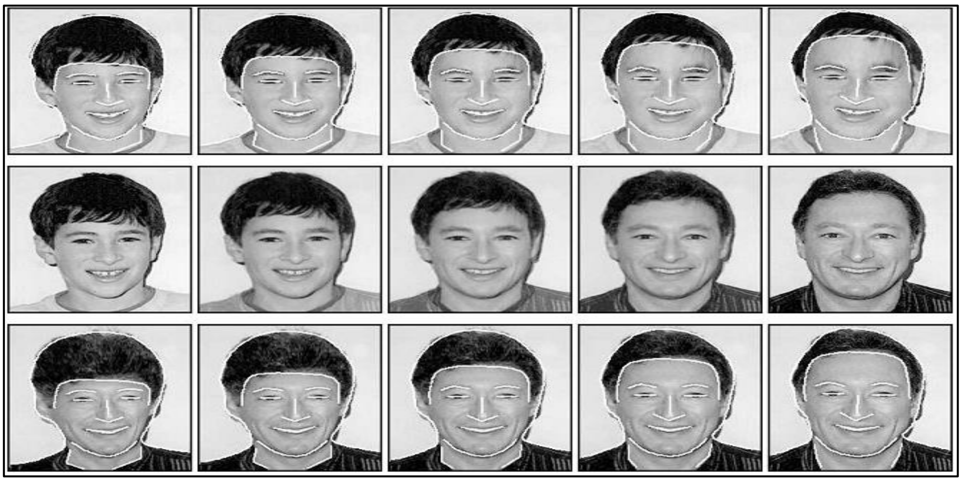

Figure 6. Example of MFFD-based morphing [2].

3.7 Work Minimization

A technique proposed by Gao and Soldberg named work minimization aims to search for some measures of (work) that can determine how easily morph [36]. The technique is motivated by polygon shape blending solving problems [37]. Work minimization algorithm can be applied and reduce human work with little or no user interaction [2]. The method considered solving cases when some similar images of the (source and destination) for warping are not precise [16]. Therefore, the proposed method is based on a work minimization strategy that derives its cost directly from the image intensities and not from user-specified constraints [2].

This approach is consistent with the choice for the warp equation of C0 bi-linear B-splines and selects the best shape blend as the one requires the least amount of work to bend and stretch one polygon into the other [36]. Gao and Soldberg, showed that in case using two images, similar images (such as two faces) in the origin and the destination image, in general, the algorithm works automatically and the result will be pleasing. The good feature of this algorithm is that it is time-saving. The work minimization technique is a similar semi-automatic approach but aims at images with similar colors [38]. According to the author, the drawback of this method there a slight ghosting artifact may occur. An example of this method with five anchor points is shown in Figure 7.

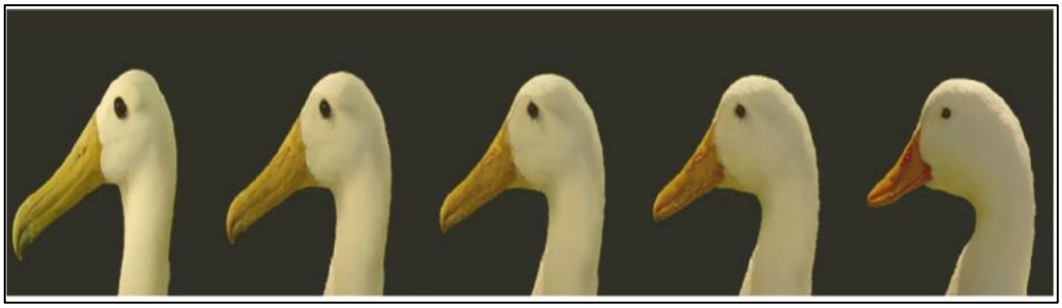

Figure 7. Example of work minimization morphing [38].

3.8 Morphing Using Structural Similarity

Knowing that the main factor for accurate image morphing is selecting a map between images in a way that leads to precise fitness between the images. A new technique for automatic mapping proposed by Jing et al. [38] by optimizing the compatibility of corresponding warped image neighbors, based on adaptive structural similarity, the authors exploited the benefits of similarity energy and modified similarity index presented by Wang et al.in [39]. The modified similarity metric was adopted to measure the neighborhoods with the same structure if they have similar edge structures, considering distinct color distributions and geometric distortions. Inspired by Yang et al. work in [40]. Jing et al. technique used an efficient and simple backward-mapping approach to render intermediate frames for morphing. They proposed a fast interactive per-pixel search technique to invert the mapping. The method parameterizes the map over a halfway domain correspondence establishing, it also supplies a technique to handle simple occlusions that do not affect the optimization process. Also, Liao et al explained a method for motion path improvement by applying a quadratic path optimization in order to reduce deformation during morph operation. The authors compared this approach with other morphing techniques, where the resulting image is more accurate than the former morphing methods. According to the author in [38], the adopted similarity energy can manage more generic morphs of scenes with various colors, and the result is excellent if compared with the results of the work minimization approach. As in the previous method, the proposed method does not need mesh rasterization, since every pixel in an intermediate image is evaluated independently, also, the proposed technique is capable to generate images that can cover the whole domain of the input, unlike mesh-based approaches [38]. The next figure 8, presents an example of a morphing sequence using a structural similarity approach.

The three middle images are the midway morphing images of the input images shown on the figure's left and right [38].

Figure 8. Morphing result using structural similarity [38].

3.9- 3D Face image Morphing

To keep up with the continuous development on 3 dimensions (3D) graphic technique, Yang et al. [40] presented a new technique applied to two face images to present 3D face geometry morphing, produced from the same images of different persons, which is very difficult work because people face is not similar nor fixed, where the same face differs in each expression or position. This method is inspired by the regenerative morphing approach [41], which generates automatic morph on images have different objects, using a traditional warp, where the blended approach is replaced with a regenerative approach and the output sequence produced by the small pieces of the source images in a patch-based [41]. In opposition to it, the proposed 3D image optimization works on a frame level instead of a patch base. The developed techniques operate fully automatically on the same face or two different faces and aim to use two different of different poses or expressions to generate optimized high-quality face morphing animation.

The proposed technique applies warping independently on two faces and only roughly using a 3D model-based flow, which is different from the classic warping techniques that are applied for morphing operations that need accurate correspondence of the source images, so Yang et al. adopted this warping method aims to overcome common warping like “holes” and fold overs, they applied optical flow based interpolation to warp the background outside the face area by interpolating per frame flow, the method does not involve mesh or triangle rasterization, since, each pixel in the intermediate image is evaluated independently. The first step in the developed system requires, extracting facial landmarks from the input pictures, and projecting the picture on a subspace learned from an external face shape dataset in order to recover the 3D face geometry. To improve morphing sequence quality, the authors defined a morphing energy function, and also employed an iterative optimization approach to minimize it [40]. Figure 9, presents an example of the optimized 3D face morphing method.

Figure 9. Example of 3D Morphing using aware appearance optimization [40].

It should be noted 3d image morphing is also used to blend 3D human faces into different structures such as animals, but the problem with this morphing is their faces structures and feature are totally different. Later Yan et al. presented a new technique for building semantic-adaptive correspondences between human and animal faces which helps preserve human features better [42]. The proposed Alignment-aware 3D Face Morphing framework applies morphing using an alignment-aware controller mesh using controller-based mapping, which builds multi-density correspondences between the source controller and the target controller according to the importance of semantic information [42]. In fact, 3D image morphing techniques have developed rapidly in the last few years, Egger et al. in [43] presented a detailed survey of 3d image morphing techniques and challenges over 20 years starting from the first proposed method. Although developing efficient 3d image morphing increased the resulted image quality, it recently caused a critical security issue, especially if an efficient morphing attack is used, as explained in [44] the authors presented a novel morphing attack, aiming to improve the image visual fidelity, the authors also measured the effectiveness of morphing attack detector, demonstrating that their method is difficult to detect. Thus, detecting forged images became a very important field of study in [45] the authors proposed a technique for detecting a single morphing image attack, using patterns and analyzing the principal component, which produced a good result. Good image segmentation algorithms may also be useful to classify the object or spaces in the image as explained in [46], that can help to detect forged image. So, the competition between the attacker and the detector is contiguous using different techniques including image morphing.

4- **Conclusions**

Morphing algorithms have become an important technique not only for graphic and animation design but for various applications, especially those that require predictable results. However, there is a lack of research that surveys morphing techniques, thus a sincere attempt is made in this research to review different morphing algorithms and highlight their character with the advantages and limitations. In general morphing, algorithms share basic steps such as selecting image features, warping, and interpolation operation. The classic morphing techniques, cross-dissolving mesh warping, triangulation, and field morphing can be considered as the classic methods that became almost the base or essential for the newly developed morphing techniques, where modern techniques get advantages of these methods to be developed or merged with other classic or proposed technique to produce better results with less noticeable visual artifacts. energy minimization algorithms opened the way to innovative new methods such as MFFD, that overcome the drawback of the classic algorithms. While work minimization introduces a new technique for image morphing that was inspired by many types of research to design very efficient morphing algorithms, such as using structural similarity to present the best result. From the reviewed method, it is clear that 3D morphing will be dominant in the next few years.

Morphing algorithms vary in the resulting image quality in addition to their computation complexity that affects the execution time, thus the designer or researcher must compare these methods' specifications (strength point and limitation) and adopt the most compatible algorithm for the required application. All the presented algorithms can be emerged with other morphing algorithms to generate a new hybrid method using deep learning for example to produce a good warp and morphing for future works. After viewing so many papers it is clear that more study in this field is required to investigate improving an object's transformation process and simultaneously strengthen manipulated image detection techniques.

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