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White Paper

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Facial Recognition

A Primer

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Abstract

Today, facial recognition technologies are gaining more importance with potential applications being developed for identification, authentication and artificial intelligence purposes across different industry verticals.

This white paper provides a holistic approach towards the technology, various applications, standards and challenges that are faced in this area. This paper also provides an overview of algorithms for 2D and 3D facial recognition methods. It is expected that firms interested in exploring the facial recognition technologies, user experience experts, and information technology professionals will consider this work to be useful as an introductory treatise.

Facial recognition is the process by which the human brains remember and recognize the human faces. They use both the deductive and inductive logic in recognizing a face. However, the process that happens naturally within human brains is not trivial when carried out by computer systems. Facial recognition, as an emerging technology has many promising applications, and is predicted to become as ubiquitous as fingerprint recognition today. Also, several attempts being made to improve the facial recognition accuracy of computer systems.

Facial recognition is an important field within biometrics and computer vision. With biometrics, we can more reliably identify or authenticate a person. In this context, facial recognition can provide a user friendly way of recognizing a person by capturing the person's face using a camera attached to a computer system. A notable advantage of facial recognition over other biometric recognition methods is that it is less cumbersome for end users, for example, as compared to fingerprint recognition, palm prints, iris recognition and retina scans. On the other hand, computer vision (branch of artificial intelligence) aims to provide the means for machines to visually perceive the environment the way humans do. By means of facial and expression recognition, computer vision can help machines to recognize as well as interact with humans more effectively.

This white paper presents a holistic view of the challenges, technology, standards, and industry applications of facial recognition. It is also intended to be useful for organizations exploring the use of biometrics in improving branding, customer experience, and operations; and for user experience experts who are looking at alternatives for improving the human-computer interaction. It can also serve as a jump start for software professionals interested in exploring this technology.

Holistic Perspective

The security threats and challenges posed in the current world necessitate the need to have a reliable and robust method to identify and authenticate people. Authentication implies granting people access to a physical area or computer system based on the proof they provide for the identity they claim. A person can be authenticated based on:

(1) Something the person knows- For example, passwords and PIN numbers.

(2) Something the person is - For example, identity cards and security tokens.

(3) Something the person has – For example, biometrics.

Biometrics is being used increasingly nowadays as a reliable method of providing valid authentication over the traditional methods such as passwords and tokens. Biometric authentication relies on identifying people based on certain specific biological characteristics such as fingerprints, face, iris, retina, and a person's signature that change less frequently over a period of time. Biometrics can be used along with other categories of authentication, that is, something the person knows or has. This is termed as multi-factor authentication.

Facial recognition offers several advantages over other biometric identification and authentication techniques, as facial recognition systems have the following advantages:

- Non-intrusive and hence more convenient.
- Hygienic as no physical contact is involved
- Easy to use as only need to face a camera.
- Covert and hence useful for surveillance.

These advantages make facial recognition suitable for a wide range of applications across industry verticals, which are discussed later in this paper. Furthermore, there are quite a few interesting biometric fields closely related to facial recognition, which significantly broaden the utility of this technology as follows:

Face Detection: Involves the identification and location of human faces in a given image or video stream and is a necessary prerequisite for facial recognition.

Facial Expression Recognition: Involves the detection of physical alterations in facial components or changes in facial pigmentation in order to ascertain non-verbal communication signals.

Facial Gender Determination: Ascertaining the gender of a person based on gender-specific facial features.

Facial Age Estimation: Involves arriving at the approximate age of a person based on facial variations common to different age groups.

Facial Ethnicity Estimation: Assessing the ethnicity of a person based on common facial features found in different ethnic groups.

Indeed, there are many interesting details that can be extracted from the face, which point towards a wide variety of potential applications.

Process Overview

Facial recognition is achieved by means of comparing the rigid features of the face, which do not change over a period of time. It can also be achieved by comparing other parameters such as skin tone against the information that are stored in the facial database. Many different algorithms are already available to perform this comparison. However, the basic steps remain the same. As illustrated in Figure 1, facial recognition involves the following:

1. Acquire: This step involves capturing the image containing the face. In case of 2D facial recognition, a digital camera is needed. For 3D facial recognition, an additional range camera is needed for obtaining the depth coordinates.
2. Detect: Face detection involves identifying the face in the captured image and demarcating it from the image background.
3. Align: The face may not be completely perpendicular to the camera and hence the alignment needs to be determined and compensated for before recognition.
4. Extract: Facial feature extraction involves a process of measuring various facial features and creating a facial template, face print, for the purpose of matching and identification. The parameters that can be used for creating the facial template includes the following:
    a. Distance between the eyes
    b. Width of the nose
    c. Length of the jaw line
    d. Contour of the nose
    e. Contour of the chin
    f. Contour of the eye sockets
    g. Skin texture (skin print)
    h. Skin tone
    i. Facial geometrical mesh
5. Match: This involves the process of matching the 2D or 3D facial template with the records in the facial database. Matching often involves a scoring process. These scores

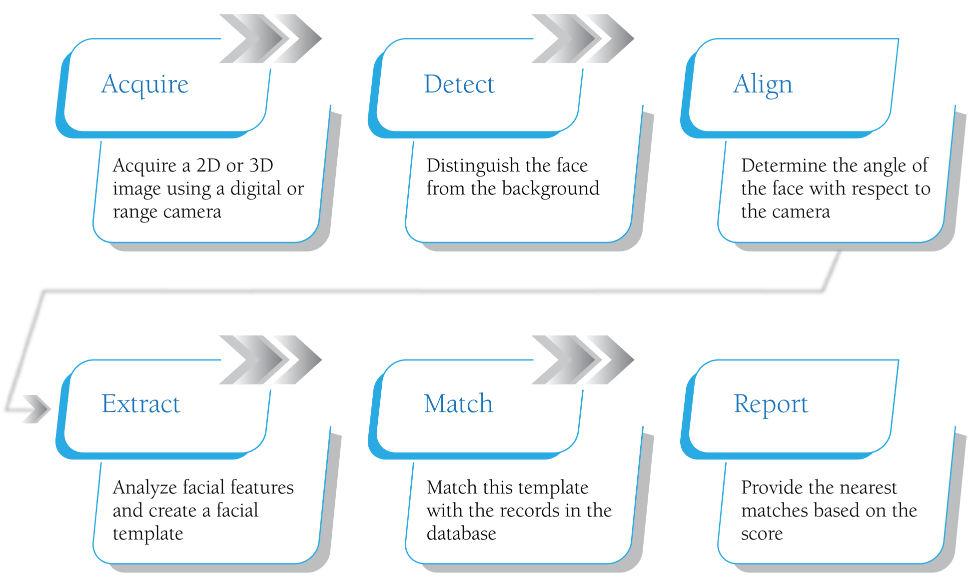


Figure 1: Facial Recognition Steps (Source: Infosys research)

Source: Infosys research

are obtained by running the corresponding algorithms on the facial data. The higher scores indicate a higher probability of the match being accurate.

6. Report: Reporting may involve returning one or more facial matches depending on the usage scenario. Matches can be returned based on the score and user preferences.

In certain situations faces need to be recognized from a live video steam, for example, in surveillance scenarios or where demographics need to be captured. In such cases, the system captures the individual static frames from the video, creates facial templates from them, and performs a comparison.

Algorithms

At its core, facial Recognition is essentially image comparison. These images are of two types. The first type is the regular RGB images such as JPEG, and PNG.2D face recognition algorithms work with these images. The second type is the one that has depth information. RGB images are obtained from normal digital cameras and depth images are obtained from devices like range cameras. The first set of algorithms which work with the RGB images uses the principles of digital signal processing to achieve the expected matching. The second set of algorithms work with depth images to do the matching. Some of the algorithms which work with the RGB images are listed below. The algorithms that use the RGB images for recognition are also referred to as 2D algorithms. Some algorithms which work with the 3D images are listed in subsequent sections.

In the evolution of facial recognition algorithms, the first set worked with the RGB images. The second set which are the 3D algorithms, consider the geometry of the facial surface. The latest algorithms being used these days tend to use a combination of both the algorithms.

2D Algorithms

Principal Component Analysis Method (PCA)7

- This is derived from Karhunen-Loeve's transformation. A. Pentaland and M. Turk proposed the Eigen face method based on PCA in 1991. This method is the golden standard for face recognition algorithms. The key implementation steps are:
  - An initial set of face images is obtained. This is called the training set.
  - From this training set, a set of M Eigen faces are calculated. This is called the face space.
  - Then the M dimensional weight space for each individual is obtained by projecting their image on to the face space. For a new image, the set of weights is calculated by projecting it onto the face space.
  - Determine if the input image is a face or not by observing the closeness to the face space. If it is sufficiently close to the face space, it is recognized as a face.
  - Based on the weight pattern obtained from the projection, this is classified as a known face or an unknown face. The new face can then be used to update the face space if needed.
  - Let us try to understand this through a simpler domain. Consider a normal 3D space defined by a coordinate system. If we have the unit vectors x, y, z representing the system then any vector in that space can be a linear combination of these vectors, for example, a vector R=5x+6y+3z, where R is expressed as a linear combination of unit vectors x, y, z with their respective weights being 5, 6, 3. The face space discussed above is similar to the vector space described here. It so happens that we construct it from known faces. There are a set of M Eigen faces defined here just like unit x, y, z in 3D system. Once we have a face space with Eigen faces then we try to express any face as a linear combination of the Eigen faces. Similar to the defined vector R. In the 3D system, we have numbers as coefficients to the unit vectors x, y, z. In fact these can be functions when we are dealing with face space. The new face is expressed as a linear combination of the Eigen faces. Depending upon the nature of weights, that is, the coefficients, decisions are made as described above.

Independent Component Analysis (ICA)3

- Bartlett et al presented this method for facial recognition. The main goal of ICA is to enhance the PCA standalone performance mentioned above. ICA provides discriminant analysis to PCA by considering the higher order moments not considered by PCA thereby making it more powerful.

Linear Discriminant Analysis Method (LDA)3

- LDA is another approach to face recognition which considers the discriminating capability of facial features. For example, the facial region having the eyes and the region having the nose and lips have greater discrimination capability. LDA deals with secondary selection from the PCA vectors, based on the discrimination power to find the Eigen features.

There are various other algorithms that deal with the facial recognition such as Kernel Methods, Support Vector Machine Methods, Hidden Markov Models, Eigen Space-based Adaptive Approach, Active Appearance Models (AAM), Trace Transform Methods, Bayesian Framework, and Boosting and Ensemble Solutions. For more details, refer to http://www.face-rec.org/algorithms.

3D Algorithms

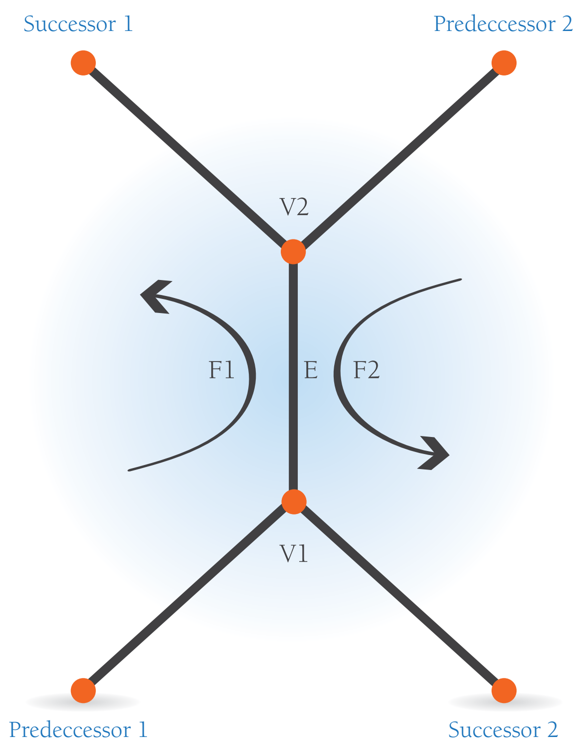
Algorithms which consider the three dimensional aspects of a face are discussed below.

The following are different ways of getting 3D facial surface data:

- Extrapolation from RGB images: One way of getting a 3D facial surface of an individual is to generate it. It is possible to generate 3D facial surface from multiple 2D or RGB images. There are algorithms and techniques to do the same. These algorithms attempt to calculate the depth map from multiple 2D images. Since this method deals with calculations, the resultant data is an interpolation and is prone to errors. There are more robust methods for obtaining 3D facial surfaces which are discussed below.
- Procedure to get the actual 3D facial surface: The devices that are needed to capture 3D facial data are depth sensors, range cameras, time of flight cameras, or infrared cameras (all these serve the same functionality). Microsoft Kinect can also be used with a PC to capture 3D facial surface data as it has the required sensors.
- The images obtained from range cameras are not RGB images. These cameras capture depth maps. The cameras emit IR rays and capture the reflected rays. The time taken by the ray to travel back helps in calculating the distance of a point on the surface from the camera. Hence these cameras are also called time of flight cameras. The pixels in these images contain the distance information, that is, the distance of the camera from the surface that reflected the emitted ray. The distances of all the points on the reflecting surface are captured. These distances vary according to the surface contours of the object whose image is being captured. Initially the cameras may need calibration and verification for accuracy. Only after the initial calibration, the experiment must be conducted for capturing the facial data. The device emits the raw data which must be captured by the PC.
- Once the raw data is captured, it must be converted into 3D point cloud. The algorithms and the constants used to compute this depend on the ToF camera used. There are certain open sources available to compute the 3D point cloud. The facial surface is sampled by the device through its ToF camera. The number of points in the point cloud varies from device to device. This depends on the number of points of the face the device is sampling. If the number of points sampled is higher than the resulting data of the point cloud is high.
- After obtaining the 3D point cloud, adopt the techniques of Delaunay tetrahedralization to compute the geometrical meshes. Relevant algorithms are available in the references section. A significant amount of cropping and smoothing may require before proceeding further. The creation of the mesh can be done in multiple ways. A straight forward way is to create a rigid geometrical mesh. The other way is to embed the facial surface using principles of isometric embedding without disturbing the intrinsic geometry of the surface. Such an embedding removes the dependency on extrinsic geometry associated with the surface. Extrinsic geometry of the surface deals with how the surface is embedded in the ambient space. Intrinsic geometry is the geometry on the surface itself. In this procedure one can choose an embedding space. Two surfaces which are a result of isometric embedding in a space are called canonical representations. These two surfaces are said to be isometric to each other if the distance between any two points on surface 1 is equal to the distance between the same points on surface 2. Isometric representation of the facial surface allows us to consider the facial expressions while recognition. Facial surfaces captured while a person is smiling or crying can be treated as isometric to each other. Extreme expressions are not strictly isometric but this treatment is much better compared to the rigid geometry model. The advantage of isometric model of a facial surface is that it preserves the geodesic distances between vertices. Expression invariant face recognition has to do with isometric embedding of the facial surface

in space and using other Isogeometric principles for recognition.

- Embedding facial surface in a selected space: Let us consider a facial surface that is represented by a collection of points in 3D. Geometrically, it is a metric space with finite set of points. Let this be called space F1. Define a matrix D1 whose element d1ij is the distance between the points i and j. Now, define a transformation such that resultant metric space F2 preserves the distance matrix D2, that is, d2ij = d1ij for all the points in the space. Such a transformation is called canonical transformation and is used for isometric embedding. F2 is said to be a canonical form of F1 and is an approximate representation of F1. It is possible to find an optimal canonical form by choosing the right metric and transformation. Let us consider a transformation which provides for a better comparison.
- The computation of geometrical mesh of the facial surface is completed. However, this information needs to be stored in database for future use. One way is storing it as a blob. However, this is not an efficient method when this mesh must be traversed for comparisons. Let us consider the data structures that are needed to store the data. A very useful data structure for storing 3D geometrical meshes is the Wing Edged Data Structure. This is a very commonly used data structure for storing meshes of rigid geometrical objects. Consider a tetrahedron of four vertices. It has four triangular faces with six edges. The traversal along an edge has a start vertex and an end vertex. The following diagram depicts the Wing Edged Data Structure. There is a left face and a right face of the edge in consideration. The traversal along the edge from left to right has a predecessor edge and successor edge. Similarly, traversal along the edge from right to left shows a predecessor and successor. The traversal process is also explained in the below diagram.
- This constitutes the edge table and is the main table. The other tables, face table and vertex table, have two columns each. Face and edge information being stored in one table and the other table having vertex and edge information. Such a data structure allows certain topological queries to run easily on the data and hence is preferred. There are other data structures similar to Wing Edged Data Structures with little variations such as half wing edged and so on. The choice of data structure depends upon the problem being solved.



The following algorithms deal with 3D facial surface data:

- The rigid body geometry methods: The data for facial geometric mesh of a person is stored according to the Wing Edged Data Structure. Let us call this mesh1. Another snapshot of the facial surface of the same person is available. Let us call this mesh2. The origins of both the meshes must be aligned now. This eliminates the extrinsic geometry dependency between the meshes. This is little difficult to achieve, and depends on the sensor used and the setup. Once the common origin is in place, compute the nearest distance of each vertex in mesh2 from mesh1. If the nearest distance from mesh1 for all the vertices is less than a certain predefined value, usually small, then a perfect match exists. Depending on the deviation, it can be ascertained if it is a similar mesh. In fact such an algorithm can be applied at the point cloud stage. If the origin of the point cloud of mesh1 (mesh1 is created using this point cloud) and the origin of point cloud of mesh2 are same, then point by point comparison can be made. These point clouds are difficult to be compared. The nearest distance of a vertex in mesh2 from all the vertices of mesh1 can be computed. This can be called as the creation of the matrix D whose element dij represents the distance between the points i and j. This process must be repeated for all the vertices of mesh2. If the smallest distance of all the vertices happens to be less than an agreeable predefined value, then mesh1 and mesh2 are same surfaces. The success criterion for this approach is the alignment of the axis and origin of both the meshes. The concern in this scenario is that the facial surface is sampled through a finite set of points through these sensors. There is a chance that the same point of the face is sampled at the first time and may not be sampled the next time. So the point set which is used for creating the point cloud may vary. This makes these methods unreliable. Another technique called Bending Invariant technique can be used for leveraging the matrix D for similarity computations. It is also possible to define points of interest such as tip of the nose, and beginning of nose. It is possible to compute the length of Nose Bridge, distance between the eyes, and ascertain similarity.
- Isometric embedding: A. Bronstein, M. Bronstein, and R. Kimmel12 proposed the 3D algorithms for facial recognition. There are several algorithms which deal with this topic. The previous section explained the canonical transformations of the facial surface. The choice of the transformation metric and space to embed in depend on the problem. A facial surface can be embedded on a sphere as shown by Bronstein et al. Such an embedding minimizes the error and distortion due to embedding. Consider Spherical Harmonic Transformation in order to obtain an invariant canonical form of the original facial surface. Any function in L2 (class of functions which are square integrable) can be expressed as a combination of the spherical harmonic basis with coefficients. Spherical harmonics themselves are expressed in terms of Legendre Polynomials. For more details on spherical harmonics, see References.
- A property of Spherical harmonic coefficients is that under rotation transformation the change in the coefficients occurs only in the imaginary part. So absolute values are invariant under rotation and reflection about the North Pole in S2 (top most point of a sphere). This makes the canonical representation an invariant one to rotations and reflection about one axis. Finally, the facial surface is expressed as sum of spherical harmonics with coefficients. The dissimilarity which determines if two faces are same or not is also calculated using these coefficients. It is the simple norm or sum of squares of differences of coefficients. The greater the dissimilarity value, the dissimilar are the surfaces. More sophisticated measure of dissimilarity can be obtained using weighted norm or Euclidean distance. Optimal weights can be found by training, similar to the PCA method. Experiments with few people and the respective results can be seen in the work by Bronstein and others.
- Combination of RGB images and 3D images: Pure 3D way of recognizing faces was discussed previously. For better recognition, it is better to capture both the 3D and 2D (normal image) images of a facial surface. Sophisticated devices are available in the market that can capture both the 3D and normal RGB images. Since both are captured, processing can be done separately using one set of algorithms for RGB and one set for the 3D part. It is also possible to combine and process them together. In this case, along with the x, y, z coordinates of a point, the texture is also stored. In reality it means that the exact facial surface is reconstructed from the 3D mesh and the RBG image. The RGB image is overlaid on top of the mesh. This gives an exact replica of the face. As discussed earlier, more than one way of building the canonical representations of a 3D facial surface and more than one algorithm to do a 2D facial recognition is available. In order to process the 3D as well as the 2D parts of the image together, the texture part needs to be incorporated into the canonical form. When a canonical representation of a facial surface is done in 3D then canonical faces or Eigen faces can be constructed simultaneously for the texture part of the facial surface. At the end of the computation two sets of Eigen functions -one set for 3D facial surface and another for texture part of the face- are available. Hence there exist two sets of weight functions for a face. To calculate the similarity, compute the distance using the canonical 3D set as well as the texture based Eigen set. The results can help decide on the similarity.

Comparing 2D and 3D Facial Recognition

Factor	2D Facial Recognition	3D Facial Recognition
Facial features recognized	Based on measurements such as distance between the eyes, width of the nose, and length of the jaw. Skin texture (as well as skin tone) can also be utilized by creating a 'skin print'.	Based on the contours of the nose, chin, eye sockets, etc. for which a mesh of the facial surface is used. A facial depth map is utilized to construct the mesh.
Facial expression variations	Facial recognition becomes rather difficult if the subject is non-cooperative and starts pulling faces.	3D recognition works more reliably based on the geometric principles of isometry. Different facial expressions of a person are treated as isometric surfaces.
Face orientation	Minor variations in face orientation up to around 15 to 20 degrees can be accommodated.	Faces can be recognized with variations in orientation up to 90 degrees.
Lighting variations	The face needs to be reasonably well illuminated. Poor lighting can significantly impact performance.	Range cameras with infrared light can be used in low light conditions as well.
Camera type	Web camera or digital camera.	Stereoscopic or range camera.
Reliability	Reliable under relatively controlled conditions.	Reliability is significantly higher especially when used along with 2D facial recognition technologies.

While 3D facial recognition is considered to be more advanced and reliable, it is generally recommended to use a mix of 2D and 3D technologies to obtain better results.

Operational Scenarios

This section enumerates facial recognition scenarios, both present and futuristic:

Industry/Domain	Scenario
Access control	Use facial recognition to provide access to: • A computer or a smart-phone • At a physical security check point of a secure facility or for a territory • Verification at an examination center
Retail industry	Retailers can use this technology for the following: • Identify Customers: To provide a personalized shopping experience. After identification, relevant items and offers can be presented • Loyalty Program: As an alternative for loyalty cards • Targeted Marketing: By identifying the gender and age, relevant advertisements can be displayed • Store Demographics: Identifying the number of people, gender, and age can help the store manage their merchandizing and setup efficiently
Travel	Some travel related scenarios are: • Immigration Checkpoint: Can be used for passenger verification and to identify known elements (security measures) • Boarding Pass Issue: Frequent fliers can be automatically identified at the counter and their boarding pass issued
Consumer banking	Facial recognition can be used for: • Customer Identification: The moment a customer approaches a bank counter, details such as the account number and balance can be displayed to the executive. It can also be used as an additional authentication mechanism during withdrawals, clearing cheques, etc. • ATM Access: Facial recognition in combination with a secret key can be used for accessing an account. • Vault Security System: It can be used as an additional mode of security to authenticate customers.

Industry/Domain	Scenario
Public surveillance	Facial recognition technologies can play a very important role in public surveillance. By using the video feed from public surveillance cameras, facial recognition can be used for the following: • Locate Missing People: Especially children. • Identify Criminals and Terrorists: It can be used by law enforcing agencies. • Identify Hooligans: It can be used in large crowd gatherings such as sport events or music concerts. • Identify Changes: Identifies how the person can possibly look after few years. It can help track criminals over time.
Time and attendance systems	Facial recognition can be used in a biometric time clock system to keep track of attendance and working hours of employees. This can prevent 'buddy punching' where colleagues registers the attendance of the employees.
Photo tagging	Once tagged, the facial recognition software automatically identifies the people in pictures without the need for tagging them individually. For example Picasa.
Machine perception	Within the field of artificial intelligence, recognizing a face provides a way of identifying a person and facilitates the intelligent system to carry out social interactions accordingly.
Astrology	Reliable under relatively controlled conditions.

Extant Standards

In recognition to the growing importance of public security, effort is being made to define standards related to facial recognition technologies. Currently, all the vendors of facial recognition systems are not compliant to the following standards:

1. ANSI/INCITS 385-2004

   This ANSI standard defines the properties and attributes of the facial image captured. In addition, it provides standards for image data interchange to promote interoperability between computer systems.

2. ANSI/NIST-ITL

   The current standards are ANSI/NIST-ITL 1-2007 and ANSI/NIST-ITL 2-2008. These standards are being updated and are called ANSI/NIST-ITL 1-2011. This covers the interchange format for biometric data, including fingerprints, facial images, scars, marks, tattoos, iris image, and palm-prints.

3. ISO SC37 19794-5

   Provides a set of standards for facial recognition including how a facial photograph should appear, the conditions for taking photographs, and three dimensional facial image data interchange formats.

Key Challenges

Unlike object recognition, facial recognition is lot more challenging as facial features undergoes variations over time.

2D
Facial Recognition

Even minor variations can lead to incorrect results. The inclination of the person's face with respect to the camera or the distance from the camera usually has some variation, which must be considered during recognition. In addition there may be differences in lighting conditions and the background in which the person's face is being recognized, which may lead to difficulties in recognizing the face. Apart from that, there exists the issue of variations due to make up, moustache and beard, hair style and accessories such spectacles, hat, etc. Each of these poses issues in the ability of the system to recognize a person.

3D
Facial Recognition

While using 3D algorithms, the processing capability is a challenge as lot of computation power is needed to do the geometrical mesh processing. However, with cloud computing becoming more popular, computation power limitation may not be such a major issue in future.

Conclusion

Facial recognition is an upcoming area. There are a lot of potential scenarios where it can be used. However, it also has challenges as listed in the previous section. Considering this it is not completely reliable to be used as an independent technique for authentication. Facial recognition may be thrown out of gear with plastic surgery, so it might need to be combined with other technologies such as Iris scan to improve reliability. With improvement in tools and technologies, it is only a matter of time before the incidence of false identification of subjects is reduced to an acceptable level to make facial recognition more useful.

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