Chapter 2

Review of Related Literature

2.1. Introduction to review of related literature

To review the literature on human face and reconstruct human face in 3D environment it is necessary to study the selected topics of various streams that focus on human face. This study will enable us to understand the various thoughts, philosophies, experiments, findings and inferences gathered by mankind over many centuries. The consolidated analysis of these thought processes will become the crucial input for emerging system. The researcher's path begins from there onwards to give the unique path for the design of most suitable and applicable facial reconstruction system.

2.2. Various streams related to study of human face

At a very broad level two manmade divisions of human activities are art and science. Art is subjective, based on emotions and synthesis of thoughts whereas science is rational, objective and analysis of thinking. Art deals with aesthetic pleasure without utilization value on the other hand science finds purpose in every action. Human face study was initiated by art stream and then scientific analysis started in the renaissance. In 18th century with the revolutionary development in science emerged many diverse streams. There is immense information on human face scattered in different pockets of these new streams. As discussed in chapter 1.2 motivation, there are many aspects of human face. There are fields dedicated to study every individual aspect of the human face.
In last 50 years, each field has opened up many new avenues and super specialization has become the trend of industry.

![Diagram of Science Streams]

Researcher feels that understanding of few streams is necessary which are linked with study of various aspects of human face. Researcher mentioned below various streams and their scope which explains their relationship with human face study and its reference in the proposed research study. (http://en.wikipedia.org/wiki/Main_Page)

### 2.2.1. Statistics

Statistical analysis is used to deal with vast numerical data relating to groups of individuals or experiments. It helps to reveal all its aspects including collection, analysis and interpretation. To construct a head model representing Indian population researcher considered the variations in dimensions of each facial feature. Along with mean, standard deviation and other terms of this data collection were studied under mathematics and statistics. Researcher is referring the statistical findings based on Indian anthropometric dimensions listed in chapter 3.5.1.3.

### 2.2.2. Genetics
Genetics unfolds the mysteries of heredity and variation in various Human communities. Researcher found the explanation of biological aspect of Human race in genetics and its descendent anthropology. As the focus of proposed thesis is only on Caucasus race in Indian subcontinent, researcher will have to get the appropriate knowledge so that distinction and definition of the feature will be decided. In section 2.3.1.2, researcher has noted the genetic factor in the shape of facial feature.

2.2.3. **Anthropology**

Anthropology unveil human origin, their behavior and classification into various physical, social, and cultural patterns. Biological or physical Anthropology refers to the bio-cultural human diversity. Anthropometry is the study of physical measurements of human individuals which helps in understanding variations in various aspects. It is discussed further in chapter 2.3.2.2.

2.2.4. **Biological morphology**

Under bioscience stream, biological morphology scrutinizes form, structure and configuration of an organism. Geometric morphometrics has collection of methods that deal directly with the coordinates of anatomical landmarks, either in two or three dimensions, rather than with traditional distance or angle measurements. Researcher analyzed various shapes of facial features and ideated blend shapes for facial reconstruction in the proposed system. Researcher discusses the shape variations in chapter 2.3.1.2, 2.3.1.3 and 2.3.1.4.

2.2.5. **Anatomy**

Detailed documentation on the structure of human skull, muscles can be found in a special branch of medicine that is Anatomy. In order to reconstruct the face researcher noticed that actual understanding of construction and function of human face is utmost important. The current trends and some fundamentals related to facial reconstruction are mentioned in 2.3.1.
2.2.6. **Embryology**

Human face is formed in early stages before birth. Embryology uncovers the details of development of an embryo from the fertilization of the ovum to the fetus stage which shows facial formation. It is very important to know how we get these facial features and the abnormalities in the formation of facial features. Related study and findings are listed in chapter 2.3.1.1.

2.2.7. **Osteology**

Human face shape is basically elevation on skull. Osteology, a branch of anatomy reveals all aspects of bones. (Sub discipline of anthropology and archaeology). Human skull and its readings are discussed in chapter 2.3.1.3.

2.2.8. **Orthodontics and Odontology**

Lower face surface is greatly influenced by the dental arrangement. Orthodontics, the branch of dentistry dealing with the prevention or correction of irregularities of the teeth and Odontology also known as Dentistry reveals dental arrangement, soft and hard tissues of the jaw (mandible), the oral cavity, maxillofacial area. Researcher’s analysis of jaw, mouth and cheekbones is stated in Section 3.5.1.2.4.

2.2.9. **Forensic science**

Forensic science is the application of scientific knowledge and principles to investigate crime. Forensic science helps presentation and interpretation of scientific information in court. A forensic scientist has a vital knowledge to examine and determine the meaning of physical evidence and forensic art uses the artistic skills like composite drawing, crime scene sketching, image modification and image identification and facial reconstruction aids. Forensic anthropology studies the analysis and identification of human remains. Forensic odontology is the study of the uniqueness of dentition for
age identification and identification of person to help legal system. Ante mortem and Postmortem study leads to gender, age and race determination. Facial reconstruction is the application of forensic science, which is commonly used technique for visualization of face. Review of various Facial reconstruction systems can be found in section 2.5.

2.2.10. Rhinolaryngology

Nose and ear shows wide range of variations that are difficult to analyze. Rhinolaryngology deals with ear, nose and throat. The anatomic structure of nose and ear covered in detail in this branch, helped researcher to design parametric model of nose (Section 3.5.1.2.2) and ear (Section 3.5.1.2.5).

Biometrics comprises methods for uniquely recognizing humans based upon one or more intrinsic physical or behavioral traits. Many facial recognition/detection systems refer the facial biometric data, apply various algorithms to compare with existing vast facial database to identify individual. Facial reconstruction system should understand how to uniquely construct a facial model so that it can be identified.

2.2.11. 3D Computer Graphics and Modeling

3D Computer Graphics and Modeling deals with graphics that use a three-dimensional representation of geometric data (often Cartesian) stored in the computer for the purposes of performing calculations and rendering 2D images. 3D modeling is the process of developing a mathematical representation of any three-dimensional surface of object. Basically there are 2 categories: solid models and boundary or surface models. In the proposed system a 3Dimentional human head surface model will be created. In depth analysis of these techniques is presented in the chapter 3.1.6.7 and detailed analysis of the human head is mentioned in the chapter 2.3.1.3
Fig 2.3 Human Face study in Art and Other Streams

Researcher has observed the vast collection of art and referred books and literature on various artists. The chapter 2.3.2 throws light on many virtuosos and their great contribution to the study of human face. Some established canons by these artists are used as basic principles to design the concept of AdarshMudra (Section 3.6.7).

2.2.12. Psychology

Psychology – Neuroscience deals with the nervous system activity related to perception of face. Various psychologists have studied, experimented and noted results on mental imagery, perception and operational principle of human brain. There are few controversial and unproved results; hence researcher does not fully bank on any particular result. Researcher noted few important points related to facial perception in section 2.5.1.1.2.

2.2.13. Criminology

Criminology studies the crucial aspects of criminal investigation such as Facial Recognition, Detection and Identification are discussed in the proposed thesis.

Researcher is not going into the details of each branch but touching only those topics that are necessary to develop facial reconstruction system.
The outcome of every branch is evolving continuously. In order to predict one particular face we might have to define hundreds of variables and establish their relationship. Researcher feels that the correctness of modeling of the face directly relates to the right approach and right input to correctly define of each variable. It might be very difficult and expensive because definition of one parameter might require information from different streams. For example, it might be very expensive and some times impossible to gather the whole genetic family structure as an input. Still we can consider some serious norms and see how best we can support it.

2.3. Taxonomy of Literature Based on Theories
Theories help us understand the construction, functionality and various aspects of face. After gathering the absolute knowledge from each field researcher thinks that the critical analysis of various approaches and industrial applications should be tested. When we actually build a system and cross check the outputs then many obscure and unknown details are revealed. A good implementation always stands tall as perfect theory. Most of the limitations of system are either due to technical problems or feasibility of the solution. There are many terminologies while stating the theories about human face. For example: facial modeling, facial simulation, facial detection, facial identification, facial recognition, facial reconstruction, craniofacial reconstruction. At a first glance it is very confusing and looks ambiguous but if we read each theory carefully then it reveals author’s exact line of thinking. To design a 3D reconstruction of human face system the most important step is to categorize all the data into different streams and then analyze each one with their connection with other streams.

Images captured by camera go through complex algorithm to find out known people. Faces are matched with target nodal points referred by the distance between eyes, width of nose, depth of eye sockets, cheekbones, jaw line and chin. Crime department takes the help of these systems for facial recognition but knowledge database will certainly be useful for our system.
Fig 2.4 Taxonomy of Literature Based on Approach
2.3.1. Facial Anatomy/Surgery

Darwin’s theory of evolution proved that from last millennia facial anatomy is adopting gentle changes. The anatomy also changes due to other reasons like malformation, growth, accident or surgery. A look of a face can be drastically changed by various surgeries. Since last 20 years Facial Surgery has seen unprecedented development. Many new techniques added like facial plastic surgery, orthognatic surgery. Surgeons operate on different parts of face; these surgeries include nasal surgery (Rhinoplasty and Septoplasty), Face lift (rhytidectomy), Skin peeling, Lift and peel, Eyelid surgery (blepharoplasty), Brow lift, forehead lift, lip correction, Ear surgery (otoplasty), chin implant and Neck muscle repair (platysmaplasty) and many other surgeries. Orthognatic surgery is surgery to correct conditions of the jaw and face related to structure, growth and other problems. All these surgeries directly modify shape and size of facial feature which changes the entire look of a person. Preoperative simulation of plastic or orthodontic surgery will play a great role in near future. The study and results will be immensely useful for both practitioners and patients.

2.3.1.1. Anatomy of facial Features

The face is the anatomical feature which is truly unique to each human, though the basis of its general development is identical for all humans and similar to that seems for other species. First of all we will have to see the face formation and normal and abnormal development during the embryonic and fetal periods. Face Development will be best explained with help of Carnegie stages.
Fig 2.5 Carnegie Stages of Human Development

[Ref: Human Embryo Face (Carnegie stages, Kyoto collection), UNSW Embryology, Prof. Kohei Shiota]

Carnegie stages are named after the famous Institute which began collecting and classifying embryos in the early 19th Century.

Face develops from week 4 to week 10. The steps are as follows

Fig 2.6 Human Embryo Face (Carnegie stage 16 to 18)
begins at week 4 centered around stomodeum

ii. external depression at oral membrane

iii. forms forehead, nose dorsum and apex

iv. paired maxillary prominences: form upper cheek and upper lip

v. paired mandibular prominences: lower cheek, chin and lower lip

vi. Ear Auricles

vii. Facial Prominences

The face has a complex origin arising from a number of head structures and sensitive to a number of teratogens during critical periods of its development. The related structures of upper lip and palate significantly contribute to the majority of face abnormalities.
The human skull is almost at full size at birth. However, the cranium has not yet been compounded together. In simpler words, the skull is flexible and distorted during birth therefore making it easier for woman to deliver a baby. And, after about 24 months after birth, the bones are fused together to form the adult skull.

2.3.1.2. Genetic and environmental factors

The human species is blessed with great variety and diversity. Its rich diversity resulted from its global distribution, which caused the different populations of humanity to be geographically separated and thus reproductively isolated. Reproductive isolation enabled divergence -- the process of divergent evolution -- to occur, causing the isolated populations to evolve in different directions, developing their own distinct ensembles of genetic traits and characteristics. Race is a cultural and biological term hugely misused and misinterpreted. Researcher will be studying the races according to
variations in the facial features which are crucial input for building facial reconstruction model. The historical definition of race was an immutable and distinct type or species, sharing distinct racial characteristics.

The term Caucasian race (also Caucasoïd) has been used to denote the general physical type of some or all of the indigenous human populations of Europe, North Africa, the Horn of Africa, West Asia, Central Asia, and South Asia.

The concept of a Caucasian race was developed around 1800 by Johann Friedrich Blumenbach, a German scientist and classical anthropologist “Caucasoïd race” is a term used in physical anthropology to refer to people of a certain range of anthropometric measurements.

Researcher will be focusing on Caucasian race and mainly Indian subcontinent. There is considerable variation in ocular (Eye) anatomy specifically eyelids, orbit, conjunctiva and sclera shows racial characteristics. Ref: Racial and Ethnic Differences in Ocular Anatomy by C. Richard Blake, Wico W. Lai, M.D., Deepak P. Edward, New York, USA.

<table>
<thead>
<tr>
<th>Nose Type</th>
<th>Platyrrhine</th>
<th>Mesorrhine</th>
<th>Leptorrhine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethnicity</td>
<td>African</td>
<td>Asian or Latino</td>
<td>Caucasian or Indo-European</td>
</tr>
<tr>
<td>Skin type</td>
<td>Very thick</td>
<td>Moderately thick</td>
<td>Thin</td>
</tr>
<tr>
<td>Dorsum</td>
<td>Short, wide, concave</td>
<td>Short, wide</td>
<td>Long, narrow</td>
</tr>
<tr>
<td>Radix</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Nasal bones</td>
<td>Short</td>
<td>Short</td>
<td>Long</td>
</tr>
<tr>
<td>Nasal tip</td>
<td>Bulbous, under projected</td>
<td>Rounded, under projected</td>
<td>Projected</td>
</tr>
<tr>
<td>Columella</td>
<td>Short</td>
<td>Short</td>
<td>Long</td>
</tr>
<tr>
<td>Nasal alar width</td>
<td>Wide</td>
<td>Intermediate</td>
<td>Relatively narrow</td>
</tr>
<tr>
<td>Ala</td>
<td>Prominent flaring</td>
<td>Variable</td>
<td>Modest flaring</td>
</tr>
</tbody>
</table>

Table 2.1 Nose Type classification
Ref: Head and Neck Surgery, Lippincott Williams and Wilkins, 2006 P.2530
Above table shows the general nasal characteristics by morphology and its relation to ethnic variation. Among the nasal variation the leptorrhine (“tall and thin”) nose is associated with Caucasian or Indo-European descent.

Age determination is primarily associated with teeth. There are many papers discussing various techniques for the dental assessment of age.


Fig.2.9 Roles of Environment and Heredity in Producing a Phenotype.

Brown eye color requires phenylalanine from the diet i.e. environment factor and two genetically coded (hereditary) enzymes to convert phenylalanine to melanin, the eye pigment. People do not inevitably exhibit the phenotypes that would be predicted from their genotypes. Penetrance is the percentage of a population with a given genotype that actually exhibits the predicted phenotype. If 80% of people with the polydactyly
allele actually exhibit extra digits, the allele has 80% penetrance. Another reason the connection between genotype and phenotype is not inevitable is that environmental factors play an important role in the expression of all genes. At the very least, all gene expression depends on nutrition.

(a) Detached earlobes occur if even one allele of the pair is dominant (D). Attached earlobes occur only when both alleles are recessive (d). (b) A Punnett square (a diagram that is used to predict an outcome of a particular cross or breeding experiment) shows why such a trait can “skip a generation.” Both parents in this case have heterozygous genotypes (Dd) and have detached earlobes, but there is a one in four chance that their offspring could have attached earlobes. Each parent is a carrier for attached earlobes.


**2.3.1.3. Skull reveals race, age and ethnicity and individual characteristics**

Osteology explains how bones remain after death. Identification of the bones should be done by forensic anthropologist. In order to develop facial reconstruction system researcher gathered the following information which can be revealed from skull.

Actual topology of the face, its features varies depending on
a. Variation in the skull topology

b. Race, Age, Gender and Body Type

c. Linkage of skull-facial muscles- skin

d. Cartilage topology development dependencies

e. Soft tissues and Fat pockets on face

2.3.1.4. Male and Female Skull Differences

Fig.2.11 Skull landmarks

Ref: Forensic Human Identification, Section 5, Facial Identification, Chapter 13, Facial Anthropology and Reconstruction, pp.234

The difference in the form, proportion and measurements based on the sex is also termed as sexual dimorphism. Male and female children have similar skull shapes at birth but once children hit puberty, the differences start to appear.

Most prominent is the difference in the pelvis, owing to characteristics required for the processes of childbirth. The shape of a female pelvis is flatter, more rounded and proportionally larger to allow the head of a fetus to pass. Men tend to have slightly thicker and longer limbs and digit bones (phalanges), while women tend to have
narrower rib cages, smaller teeth, less angular mandibles, less pronounced cranial features such as the brow ridges and external occipital protuberance (the small bump at the back of the skull), and the carrying angle of the forearm is more pronounced in females. Females also tend to have more rounded shoulder blades. The identification of sex only from skull is very difficult. Typically Physical anthropologists pass on this necessary information to forensic artist for further work of reconstruction of human face.

According to Merrill Kazanjian is a contemporary artist based in New York City, Testosterone provokes certain features in males while female faces remain relatively childlike. The presences of higher levels of testosterone give men a thicker bone structure with more prominent bones. Male faces have more prominent jaw, chin and cheekbones (also known as the zygomatic arch). The physical size of the male skull is larger than the female skull. The distinctive characteristic of male skull is protruding super orbital ridge also known as brow line. Female faces have more rounded and narrow jaw line. They have the softness that male faces lack. It carries more fat than the male face especially in cheeks. Female faces tend to have thicker lips and higher arch on top lip. Female eyebrows generally sit a little high than male eye brows and generally have thinner and higher arch shape mainly due to plucking. Female nose is thinner shorter and narrower bridge and nostrils, and straighter or concave profile than the male nose.

![Male and Female Skull](image)

Fig 2.12 Male and Female Skull (Drawing courtesy of L. Schulzkump, MD)
There are a few key skull differences between the female skull and the male skull.

1. The male cranial mass is more blocky and massive compared to the females which more rounder and tapers at the top.

2. (Supraorbital ridges) The female’s brow ridge margin is sharper while the male’s is rather rounded and dull.

3. The Zygomatic bone also called as cheekbone or malar bone is more pronounced on the male skull than the female skull.

4. Antegonial notch is the depression along the jaw line. The Mandible or the lower jaw is more rounded on the female skull while the male skull is squared and heavily marked by muscle attachments. Also, the male have a deeper cranial mass than the female.

5. The supercilary arch is a smooth elevation extending laterally from the glabella (flat bone between the eyebrows) on either side, above the orbital margin of the frontal bone. This landmark of the male skull is more pronounced and larger than the female skull.

And another difference that researcher shouldn’t forget is…

“A man's face is his autobiography. A woman's face is her work of fiction.” says Irish poet Oscar Wilde.
2.3.2. Facial Beauty/Attractiveness

Beauty is the opposite of deformity. - Leonardo

As discussed in the chapter the study of facial beauty was initiated by Egyptians and then Greek and Roman artists influenced it by their sculptures and paintings. In 5th century B.C. Phidias showed the importance of golden ratio, the divine proportion is a formula for beautiful proportion.

If asymmetric perceptual factors alone were critical subjects reactions to the faces would change dramatically and significantly as a function of the two viewing conditions. Since this was not the case it is reasonable to conclude that the owner's facial physiognomy was predominant in the rating.

Facial Beauty as explained on www.beautyanalysis.com is the quality or combination of qualities in a face that evoke the perceiver a combination of strong positive emotion and a high degree of attraction. Dr. Stephen Marquardt relates facial beauty with the golden ratio (\( \Phi \approx 1.61803 \)) and designed a mask that gives the beauty quotient associated with every face. Beauty is a subjective and intriguing topic; obviously one can find many definitions. It is very difficult to get unanimous statement about facial beauty.


The difference between facial identity and beauty lies in the physiognomy of the observed rather than in perceptual asymmetries of the observer and importantly may be entirely independent of sex.

Ref: “Brain asymmetry and facial attractiveness: Facial beauty is not simply in the eye of the beholder” by Audrey C. Chen, Craig German and Dahlia W. Zaidel, Department of Psychology, UCLA, Los Angeles, California, USA, June 96
As explained there is huge need and scope for facial beautification. It is already practiced by many surgeons, orthodontists and medical professionals. Facial surgery is evolving and many new techniques are introduced all the time. Researcher will not be considering the modification factor on facial features due to surgical changes for the proposed study. Researcher clearly defined that facial Beauty and attractiveness can be inferred but is not the goal of the proposed study.

### 2.3.2.1. Factors contributing to physical structure

From the collected information from medical science researcher inferred that the physical structure of facial features depends on few parameters. As shown in the figure the factors contributing to physical structure of the facial feature can be categorized into 3 parts:

1. Formation/ Foundation
   a. Genetic Information
   b. Race
   c. Sex
   d. Morphological Information
   e. Congenital Malformations

2. Development
   a. Age
   b. Health
   c. Environmental Conditions

3. Modification
a. Surgical Modifications like dental treatment

Fig. 2.13 Factors contributing to physical structure

After this critical analysis, Researcher decided to consider above mentioned parameters to decide scope of the proposed system.

2.3.3. Facial Proportion/Measurements

Proportion is one of the basic principles of design skills embarks with comparing one to another. Measurement is the baby of proportion. Measurements are necessary in art and in science as well. Researcher believes that Facial proportion and measurements is an integral part of the face and thus proposed system will strongly support this line of thought.
Fig: 2.14 The Development of the Egyptian Grid System


(http://www.legon.demon.co.uk/canon.htm)

Portrait has always been the apex of any form of creation. Making a portrait requires a great face analyzing power and artistic process of some complexity which transforms the features into sketch or sculpture. Over the period of time many artists found out their own styles of drawing caricatures. Many styles born out of eloquent stoke of artists and evolved in a great way. The contribution of many legendary artists has given some standards to draw the character. Art and design professionals study and practice
these aspects knowingly or unknowingly. We will elicit some concealed measures to build the standard facial features library.

2.3.3.1. Contribution by Various Artists

As discussed in chapter 1.1 Human Face: An Overview, many legendary painters, sculptors engraved their perception in their artwork. In Egyptians developed the cubit (first recorded unit of length) noticed in ancient sculptures and colossal structures. In 5th century B.C. considered as classical period, Greek influenced study of proportions by great works of sculptors like Myron, Phidias, Polyclitus, Praxiteles, Scopas, and Lysippus. Lysippus established canon of proportions, eight head body which still persists. After many centuries, in renaissance Leonardo da Vinci, Michelangelo and Vesalius re-established human proportions based on scientific observations and connotations.

Great artists like Leonardo Da Vinci, Michelangelo, Albrecht Dürer, Quételet, and Sir Francis Galton defined the facial proportions. Researcher will be collecting the ideal dimensions of facial features and proportion related study and analyze it. The standard dimensions can be used to build the 3D template of human face. Virtuoso’s findings will become inspiration to design Vyaktirekha module.

2.3.3.1.1. Leonardo da Vinci

(1452 – 1519), was a great painter, sculptor, architect, musician, scientist, mathematician, engineer, inventor, anatomist, geologist, botanist and writer. Probably the earliest canon of human proportion in the Western world was stated by Da Vinci.
It suggests that the navel divides the height of the body in a golden section \((1.618:1,\) compared with 8:5 above), and is the centre of a circle enclosing the outstretched arms and legs. As well, the erect body is contained within a square bounded by the bottom of the feet, the top of the head and the fingertips of the outstretched arms held to the sides at shoulder height. The pubic bone divides the height exactly in half. Note that the figure uses the convention of eight head-lengths. This view was current in Ancient Greece and conveyed to Leonardo via the works of Vitruvius, who also influenced Michelangelo. In recent times this view was revitalized by Le Corbusier.

2.3.3.1.1. Leonardo da Vinci’s Facial Third Formula

i. The width of nose at its base should be approximately the distance between the eyes (medial canthus).

ii. The length of upper lip is about twice that of lower lip and chin.

iii. Tip - Slight Upward Rotation : better
iv. Nasofacial angle = 36 degrees

v. Nasofrontal angle = 120 degrees

vi. Nasomental angle = 130 degrees

vii. Mentocervical angle = 85 degrees

Fig. 2.16 Leonardo da Vinci – Crucial facial angles

Researcher has considered these norms up to some extent for design of AdarshMudra concept (Section 3.6.7).

2.3.3.1.2. Michelangelo

Michelagniolo Buonarroti (1475–1564) became an artist at the age of 13. Originally apprenticed as a painter, he rapidly achieved fame also as a sculptor, and later in life as a poet and architect. Michelangelo made countless drawings and measurements of the human body (living and dead, as well as Greek and Roman statues) in order to understand its shape, proportions and variations. David is the most recognized single statue in the history of art.

Fig. 2.17 Statue of David by Michelangelo

The choice of 7 head-lengths for David emphasized his youth, but was probably used to correct for distortion due to the observer’s position: David’s head is some 7 m above ground level. If rendered in ‘correct’ proportion, the head would appear too small.

2.3.3.1.3. Albrecht Dürer

Albrecht Dürer (1471 – 1528), German painter, engraver and mathematician, made a detailed study of the human form, and was thoroughly familiar with the work of Vitruvius, Leonardo and other Italian Renaissance artists. Dürer had a very high opinion of the science of proportion, bestowed much thought upon the subject, and eventually published a work concerning it. He explored many methods for constructing the human form according to their shape and proportion. He used circles, triangles, ratios and proportions, and polyhedra (a method known as stereometry), and was a pioneer in investigating the shape and proportion of the human body under the influence of ‘perspective projection’. Among these studies, he investigated the human head and its facial characteristics, distorting its shape using grid transformations.
Ref:

In 1525 he published book entitled “Instruction in the Measurement, with the Compass and Rule, of Lines, Surfaces and Solid Bodies, drawn up by Albrecht Dürer, and printed for the use of all lovers of art, with appropriate diagrams”. It was the first ever attempt to apply anthropometry and engineering perspective to aesthetics. Researcher thinks that this line of thought is the foundation of morphometric analysis which is used to design variations of facial features.

2.3.3.1.4. Adolphe Quételet

(1796 – 1874) A Belgian astronomer, mathematician and statistician.

He was a mathematics teacher has tremendous contributions in the field of mathematics, statistics, demography, sociology and criminology. Based on thousands of measurements of the human body taken from the Renaissance artists and from his own collection, defined the ‘average man’ whose measurements were the average of all measurements. For Quételet, the average was an ideal value: other measurements of the same trait were distributed about this according to the normal probability curve. The
Average represented the Ideal of the species, and deviations from the Average were considered to be ‘errors of measurement’.

2.3.3.1.5. Sir Francis Galton
(1822 – 1911), half-cousin of Charles Darwin, was an English Victorian polymath, anthropologist, tropical explorer, geographer, inventor, meteorologist and statistician.

Galton written over 340 papers and books and invented the statistical term correlation and regression from the mean. He has done pioneering efforts of applying statistical methods to the study of human differences.

Following Quételet, Sir Francis Galton showed that if any set of measurements within a population (e.g. the heights of all people) is normally distributed, then so are sets of similar measurements of any subgroup of that population, and vice versa. He showed too there is a correlation between the measurements of different parts of the body.

The relationships are important in forensic pathology and anthropology as a means of predicting the likely height and other characteristics of a body from bone measurements. More widely, such data are critical in ergonomics: the size and shape of the ‘average person’ are important in designing human environments and equipment.

2.3.3.1.6. Andrew Loomis
(1892 – 1959), the premier commercial illustrator was from the United States. He illustrated many art books mostly published by Walter Foster are great inspiration of artists.
Andrew Loomis thinks that drawing head is primarily a matter of interpreting form correctly in its proportion, perspective and lighting. All other qualities enter the drawing as a result of the way that form is interpreted. As Artist, we only see, analyze and set down. According to Loomis, there are lean faces, fat faces, big-boned and small bones ones. By the law of averages certain combinations of features are bound to reappear. For that reason people who are not related sometimes closely resemble with each other. In this Facial Analysis lies out of scope as it does not gives substantial input for the design but expects an output format from the system to work. So we design our system in such a way that it will try to meet those expectations. The Human species is blessed with great variety and diversity. Basic instincts life forms that humans also reflect are, fight for survival, and modify self to get adjusted with surrounding and reproduction to keep existence of species.
Fig. 2.20 Heads shapes Illustration from “Drawing Head and Hands”
2.3.3.1.7. **Avard Fairbanks**

(1897 – 1987) born in family deeply interested in art started study of sculptures in childhood. He had a great legacy of creative, dynamic and expressive skills inherited by family. He was awarded Doctor of Philosophy in Anatomy from University of Michigan and his topic of interest was human proportions. He spent long span in teaching sculptures and erected number of monuments in USA. His book “Human proportions for Artists” includes vast collection of illustrations of male and female figures with dimensions and shows his exhaustive study of human proportions.

![Male and Female Ideal Facial Proportions by Avard Fairbanks](image)

Fig 2.21 Male and Female Ideal Facial Proportions by Avard Fairbanks

2.3.3.2. **Study of Facial Feature Measurements: Anthropology**

Anthropometrics was first used in late 19th century in to identify criminals by facial characteristics. Francis Galton was a key contributor in this field. Along with the redundancy of Bertillon's measurements, Galton developed the statistical concept of
correlation. Anthropometry is the scientific description of the physical characteristics of the human body. Anthropology is the science that deals with the study of human culture and evolution; it seeks to produce useful generalizations about people and their behavior and to arrive at an unbiased understanding of the human nature.

Given the anthropological data the proposed Face will morph and fit to show the target personality. Anthropological graphs of individual feature will be shown and user will also be able to tweak the facial feature from graph. If the 3D model is changed then its dimension will be stored at runtime and can be seen as red dot in the graph. These cross referencing of 3D model and Feature anthropological graph will give a tremendous flexibility and fine tuning of the face.

Researcher identified reference data on physical measurements of adults of Indian origin and facial model will be based on this anthropometric dimension.

![Fig 2.22 Anthropometric landmarks with growth chart](image)

Ref: Illustration from Handbook of Normal Physical Measurements, Judith Hall, Ursula Froster-Iskenius and Judith Allanson, Oxford University Press, 1988, pp 94
Science like anatomy and anthropometry gives the precise information about the facial features in isolation but its location on the face, its characteristic and pattern is recorded.

Human proportions vary with the individual, but in classical art, the body of the ideal figure is 8 head-lengths from head to toe. Dürer favored 7.5 head-lengths in his pictures; Rembrandt used 7, while Giacometti at times used 12. The figure of David uses 7 head-lengths. In real life the adult human body is 7 to 8 head-lengths.

“A Mathematician, like a painter or a poet, is a maker of patterns. If his patterns are more permanent than theirs, it is because they are made with ideas.” G.H. hardy, mathematician

Critical findings gathered from the facial proportion study will act as foundation of facial reconstruction system. Researcher gathered few guidelines about human face that are listed below.

i. face can separated into cranial mass – even, regular Simple and curved dome

ii. Facial Mass – uneven, irregular, hard and triangular form

iii. Best guide that explains basic information like proportion systems, form concepts and anatomical facts. Here are the points that will plot our standard face.

iv. The basic head is shaped like an egg.

v. The eyes are located exactly half way between the crowns and chin.

vi. The eyes are spaced one eye length apart.

vii. The outside points of the eyes and the ends of the mouth line up vertically.

viii. The inside points of the eyes and the flare of the nostrils line up vertically.
The brow is approximately two times the length of one eye.

The nose is located half way between the brows and chin.

The widest part of the nose is equal to the length of an eye.

The brow line marks the top of the ear.

The bottom of the nose and the ear lobe are always on the same line.

The mouth stretches from the middle of the right eye to the middle of the left eye.

The mouth is one third the distance between the nose and the chin.

The cheek bones are on the same line as the bottom of the nose.

In real world each face breaks these rules.

All these “ideal” measurements vary from face to face. With these proportions a 3D model will be created and then it will be moulded using 3D tools to get the desired shape. Facial features are crucial to our identity and while we like to believe we're unique, there are a few underlying rules which apply. Researcher may use some of these conventions for the AdarshMudra concept.

2.3.4. Facial Modeling/Simulation

There are many approaches for facial modeling. Researcher is mainly interested in finding the most suitable and complete approach for facial modeling in 3D environment. Researcher reviewed many research papers to figure out important aspects like robustness, viability, accuracy, error correction and ease of use.

Generally, Computer based head modeling/simulation involves determining geometric descriptions and additional attributes such as surface colors and textures. For the
proposed thesis, the derived facial model will not support texture extraction and other needs of expression and animation.

It is not appropriate to categorize every research into few specified approaches as their can be a hybrid approach. The taxonomy is just for better distinction which will help further analysis. Researcher thinks that Facial modeling plays an important role in facial reconstruction system so proposed system will be embark the development on the basis of this philosophy.
Fig. 2.23 Taxonomy of Various Facial Modeling/Simulation techniques based on Approach
2.3.4.1. Interpolation

Interpolation is an old technique emerged from numerical analysis often used in sampling of data. The method comprises constructing new data points within the range of a discrete set of known data points. There are many types of interpolation such as linear, polynomial, spline interpolation etc. In computer graphics, the application of interpolation is implemented as geometric and image blending. As in the proposed thesis researcher is focusing on 3D facial model, the review will primarily focus only on geometric interpolation.

Shape interpolation is most common and simple technique to blend synthetic faces. It is also termed as morphing, vertex blending or geometric interpolation. The technique involves several different key expressions or facial data set sculpted then blended to generate a final expression. It can be worked on whole face or on particular feature. The complete mapping for each vertex makes it powerful editable tool.

The blended or modified position is the base position plus a contribution from each target whose DOF value is greater than 0. In multi target vertex gives the vector resultant as the combined target influence. Usually it is performed in local space before smooth skinning operation. Only issue with this is that it consumes lot of memory which is not preferred by game industry.
Model-fitting process: (a) a set of input images with marked feature points, (b) facial features annotated using a set of curves, (c) generic face geometry (shaded surface rendering), (d) face adapted to initial 13 feature points (after pose estimation) (e) face after 99 additional correspondences have been given.

In paper, new techniques for creating photorealistic textured 3D facial models from photographs of a human subject, and for creating smooth transitions between different facial expressions by morphing between these different models. The system can take uncalibrated views of a human subject to recover the camera poses. A scattered data interpolation technique is used to deform a generic face mesh to fit the geometry of the subject’s face. Then texture maps are extracted from recovered poses to apply onto deformed model. This process is repeated for several facial expressions from various images of subject’s face.

As interpolation is easy to use and proven technique, researcher thinks that it can be used as reliable user input for generating predictable output. Interpolation will be used to design metamorphosis between various morphologies of feature so that user will control the intensity and get the desired shape. Researcher decided to develop facial reconstruction system based on interpolation.

2.3.4.2. Vision Based

Vision based surveillance is an emerging field requires multidisciplinary expertise of signal and image processing and artificial intelligence to eliminate human operators. Vision based Facial modeling applications can be used for forensic video investigation, virtual character animation for entertainment, 3D avatars on internet, and 3D teleconferencing.

Ref: A Vision-based Approach for Facial Expression Cloning by Facial Motion Tracking by Junchul Chun and Oryun Kwon, Department of Computer Science, Kyonggi University, South Korea, KSII TRANSACTIONS ON INTERNET AND INFORMATION SYSTEMS VOL. 2, NO. 2, APRIL 2008
Fig. 2.25 Overall steps for vision-based facial motion cloning system

The system proposes real time vision-based approach for 3D head pose estimation and facial expression control for the face animation of a 3D avatar. The system initially gets the sequences of input images containing human face and then detects the face using nonparametric HT skin color model with template matching. After that it goes in two phases, Motion estimation and Expression control. Motion estimation comprises creation of cylindrical head model and projection onto the detected face. Then head pose estimation is done using optical flow motion tracking followed by dynamically updating the projected template. In expression control phase system uses the RBF (Radial Basis Function) to deform the local area of the face model around the major feature points. Finally, facial expression synthesis is done directly by tracking the variations of the major feature points and indirectly by estimating the variations of the regional feature points.

This is an effective approach to estimate head pose and track facial features for facial expression control in real time and applicable for entertainment industry. Most of the vision based systems requires video processing equipments that should be tested on
various parameters like time lapse, sequential switcher, time division multiplexing, compression options and recorders.

Basically vision based modeling depends on many uncontrolled parameters so researcher decided not to develop a system based only on vision. As digital photograph can be easily taken and used as input, researcher considered front and lateral photo as valid input for the proposed system. At the same time researcher decided not to take the responsibility of calibration and validity of the input.

2.3.4.3. Photogrammetric

Photogrammetry, as the name suggests is a technique of determining the geometric properties that uses photographs as the fundamental medium for measurement.

![Fig.2.26 Setup of cameras and projectors for Multi-Image Photogrammetry](image)

Ref: Nicola D’Apuzzo, Modeling Human Faces with Multi-Image Photogrammetry, Institute of Geodesy and Photogrammetry, ETH Zürich, Switzerland
The process is composed of five steps: acquisition of multi-images, calibration of the system, establishment of corresponding points in the images, computation of their 3-D coordinates and generation of a surface model.

The main concerns are

1. Applicable only for real objects preferable with low overlap design

2. Increasing the number of photographs will increase the accuracy of the measurement

3. To increase accuracies is to move in object closer, and take more photographs of the parts of object in sub-sections.

4. Smaller intersection angles will progressively reduce accuracies.

5. Minimum of four to six camera setup is recommended otherwise with less convergent arrangement of the cameras will give unpredictable results.

6. The object can move during the measurement as long as it moves as a rigid body. The main goal is to ensure high accuracy of the measurement and automation in the process and based on multi-image Photogrammetry.

7. Requires expensive projectors and multiple CCD cameras should be used with same calibration.

8. Takes long time to match points, still error correction required.

The system might generate some errors because of

1. Regions where the texture is insufficient because of the darkness (e.g. eyebrows) or because of the strong reflection, meshed surface doesn’t contains generates matching points. Eventually the matching process fails.
2. The regions where the projected random texture is not well focused, the matching process cannot give good results. This problem can be solved by using lenses with aperture to give a larger depth of field. However overlapping surface remains a difficult task.

The main advantage is that if configured properly it can become an automated and accurate process for measurement of the human face from multi-images. From the review researcher decided not to use the Photogrammetry as the facial modeling input. Researcher would like to point out that with the advent of technology these limitations may become obsolete. In coming future input may change drastically so system should be design independent of the input. Considering these pitfalls researcher decided not to use this approach for facial modeling for proposed facial reconstruction system.

2.3.4.4. Physically Based Modeling

Physically based approach uses the geometrically accurate shape and studies the changes in properties of facial tissues, muscle actions. The face model consists multiple layers Skull, hard solid layer at base, Muscles mounted at both ends on bones is the flexible and deformable layer, Fascia surface, Dermal-fatty layer variable tissue depth depends on health and environmental conditions and the top Epidermal surface also called as skin. Visualization of all these layers with appropriate physics properties is still an unsolved challenge for computer graphics industry. Some physically based modeling theories tries to address this situation.

Lee, Terzopoulos and Waterws designed an automated system that proposes fitting an adaptive canonical facial polygon network to scanned data using automatic techniques based on the anatomy of faces.
Fig. 2.27 Face topology construction using physically based modeling

Both dotted lines and solid lines indicate elastic spring connections between nodes.

Fig.2.27 shows (a) Triangular skin tissue prism element. (b) Close-up view of right side of an individual with conformed elements.

Few advanced systems digitize facial geometries through the use of scanning range sensors. Lee presented a methodology to automate dynamic simulation of facial tissues and muscles. Starting with a structured facial mesh, the system develops algorithms that automatically construct functional models of the heads of human subjects from laser-scanned range and reflectance data. These algorithms automatically insert contractile muscles at anatomically correct positions within a dynamic skin model and root them in an estimated skull structure with a hinged jaw. They also synthesize functional eyes, eyelids, teeth, and a neck and fit them to the final model. The constructed face may be animated via muscle actuations. The system demonstrates great realism with flexibility.

Ref: Realistic Modeling for Facial Animation by Yuencheng Lee, Demetri Terzopoulos, and Keith Waters, University of Toronto and Digital Equipment Corporation,
Researcher noticed that although physically based modeling is best approach for muscle simulation. Proposed system is not entirely physically based modeling but Jeevak concept (Section 3.6.8) will have similar features to derive the facial topology.

2.3.4.5. FEM (Finite Element Method) based

The finite element method (FEM) is a numerical approach to approximating the physics of an arbitrary complex object. [37] The target object is decomposed into element blocks representing material properties. Each element is associated with necessary physical properties of the material to visualize stress-strain relationship. The dynamic element relationships are calculated using partial differential equations and then numerically integrated using standard techniques such as Euler's method, Runge-Kutta etc. FEM is an integral part of most of the modern engineering packages for analysis and simulation testing.
Fig. 2.28 Process chart for maxillofacial surgery planning

Main goal was to approximate the physics as closely as possible and to accept higher computational costs. Therefore, the models were extended described in 3 ways:

1. Initially $C^3$ continuous finite element model of the facial surface was created using triangular polynomial shape functions. Increasing the number of finite elements resulted in a facial surface that was $C^3$ continuous.

2. System computed the external forces of the model by connecting the surface with nodal springs to the skull. The individual spring stiffness is computed by means of 3D line integration through the CT data.

3. Researcher rebuilt the model using 3D modeling software to get interactive geometric manipulation and rendering support.

The system predicts the facial shape after standard procedures in craniomaxillo facial surgery.
As shown in fig.2.29 a), b), and c) Profiles and frontal view before and after advancement of the lower jaw d), e), and f) Situation before and after surgery on the upper jaw. In figure a-c show the shapes of the skull and face before and after an osteotomy (surgical sectioning of bone) and advancement of the lower jaw bone. 19d-f shows advancement of the upper jaw bone is presented. These are some striking results obtained in the simulated surgery. Effective FEM can predict realistic results from simulations which require precise models of particular individuals based on the bone and soft tissue of the head.

Most of the physically based systems require extensive manual tuning to model a specific face with given characteristics. It produces realistic results at the cost of intensive computation to approximate human anatomy which drifts away from the exact simulation of specific person’s facial structure. Still it is a great attempt to visualize the functionality and response of facial muscles, tissues and skin topology.

Researcher thinks that it will be good feature to predict the physically based results with the face model. Jeevak phase (Section 3.6.8) will imitate artificially the physically based modeling and allow user to check the impact of various inputs onto facial tissues and modification of skin topology.

2.3.4.6. Anthropometry Based

As explained in chapter 2.3.2.2, Anthropometry is used to keep record of the physical characteristics of the human body. A great contribution in craniofacial anthropometry is from L.G. Farkas who established a database of anthropometric norms later published in book “Anthropometry of the Head and Face”.


Although Anthropometry has some loopholes, it is used as the fundamental in industrial design and reliable survey of Indian population suggests that it might be the best guideline for AdarshMudra (Section 3.6.7) design and setting the constraints in
various phases. Researcher has used Indian Anthropometric statistical analysis and check individual anthropometric dimensions inputs as setting constraints for modifications of features.

In the measurement based approach it is desirable to compare a natural signal with a synthetic signal to see how accurately it is possible to simulate the natural one.

2.3.4.7. Scanned Range Data Based

A novel approach published by Gang Pan, Wu and Yunhe Pan consists of range data registration and comparison. There are two steps in registration procedure: the coarse step conducting the normalization by exploiting a priori knowledge of the human face and facial features, and the fine step aligning the input data with the model stored in the database by the partial directed Hausdorff distance. To speed up the registration, a simplified version of the model is generated for each model in the model database. During the face comparison, the partial Hausdorff distance is employed as the similarity metric.

Fig.2.30 Fitting a plane to 3D face model
In this paper, an example of based realistic face modeling method with viseme control is considered. The researcher describes viseme as the particular facial and oral positions and movements that occur alongside the voicing of phonemes. The proposed method tries to automate the creation of a realistic face model with viseme control from a set of scanned data blending face models generated from the morphable face model by PCA.

![Fig. 2.31 Fitting mesh using PCA technique](image)

As shown in fig 2.34, process involves fitting the 2D template mesh to the image. From left to right; (a) range image (b) deformed 2D template mesh (low resolution) (c) deformed 2D template mesh (high resolution)

With the advent of technology there are many 3D scanners available that offer standard resolution scans with RGB texture maps.
Another great technological revolution in face scanning is single mesh technology from Geometric Informatics. It is currently bit expensive but the main advantages are real-time surface captured data (not tinkered) without markers which offers normal map and color texture.
In spite of all these innovations laser scanning systems still has some ambiguities due to technical limitations. The reflected laser beam may be dispersed so that the sensors can not get range or color data for some surface points. Scanned output may show missing points on the underside of the chin, nostril area, eye pupils, mouth bag and in hairline. Although it can be taken care of by manually filling the missing range and color data to get smooth shading and texture mapping.

The laser scanner produces dense spurious data with artifacts which must be refined by manual intervention. The refinement is done for various reasons such as providing the adequate details in specific areas like eyes and mouth, removal of unnecessary clumps, filling up holes and refining corresponding texture map. It doesn’t provide surface according to curvature.

Researcher will experiment with scanned data range input of an individual (Section 3.6.9.1.2) and make an attempt to use Vyaktirekha (Section 3.6.8) to modify the Mudra (Section 3.6.1) for fitting.

2.3.5. Facial Expression and Animation

For the first time in 1972 Frederic I. Parke presented “Computer generated animation of faces” at ACM annual conference, since then many research papers have attempted to generate realistic facial modeling and animation.

Human face is fundamental tool for communication. Facial expression is reflection of emotions on face and hard to isolate. In 1971, Paul Ekman and Wallace Friesen demonstrated a framework which separated universal and culture specific facial behaviors and also showed that there is no significant difference between male and female facial behaviors. They postulated six basic emotions that possess a unique facial expression. In FACS (facial Action and Coding System), facial expression is specified in terms of Action Units (AU) is considered as the foundation for describing facial expression.

Ideally Facial reconstruction system should be able to replicate the face with neutral expressions. As shown in Fig. 2.34, Generic facial expression analysis framework shows the basic elements of Facial expression and animation. Although it helped researcher to understand the Facial expression, researcher confirmed that facial expression and animation deviates from the main goal of building a neutral face. Therefore proposed system will not have any features supporting expression and animation. Researcher also assumes that any input (photographs/scans) will be free from facial expression. Researcher does not take any responsibility to tweak the input to convert it to neutral expression.
Fig 2.34 Generic facial expression analysis framework
The encircled numbers used in the system diagrams indicate relevant processing stages.


Further in a hybrid facial expression analysis system proposed by Bartlett, Larson, Hanger and Ekman integrated holistic difference-images motion extraction coupled with PCA, feature measurements along predefined intensity profiles for the estimation of wrinkles and holistic dense optical flow for whole-face motion extraction.


As researcher has already stated in section 1.12 Limitations (c), expression lies out of scope of the proposed thesis. Essentially, the reconstructed 3D facial model will not support any feature required for facial expressions and animation.

2.3.6. Facial Detection/Analysis/Identification/Recognition

“After a certain number of years, our faces become our biographies.” tells Cynthia Ozick. Humans have the natural ability to recognize and distinguish between faces. The area of the brain, the fusiform gyrus, located in the temporal lobe deals with the visual perception of facial features. While observing any face, this area gets stimulated and when person looks at that face again, recognizes it as something they have seen before. Some people find it difficult to recognize people by faces. In 1947 face blindness was named as Prosopagnosia by German neurologist Joachim Bodamer. It is a disorder of inability to recognize faces. Any normal human can recognize faces naturally from childhood. The functionality of Human brain is simulated by artificial intelligence to show the similar ability. Face is one of the most studied biometric characteristic. Typically automated facial recognition systems are developed by group of computer science researchers, neuroscientists and psychologists. In the mid 1960s, scientists
began work on using the computer to recognize human faces. Scientists believe that interdisciplinary approach will further improve the quality, so current trend is to promote technology by putting latest psychology and cognitive science researches. Ideally, Facial reconstruction system should produce a likeness of an individual which can be recognized by average group of people.

Fig.2.35 Steps in Facial Recognition System

There are two main approaches used by various scientists

1. Geometric (Feature based)
2. Photometric (View based)

Among many different algorithms most appreciated and studied in face recognition literatures are Principal Component Analysis (PCA), Linear Discriminant Analysis (LDA), Elastic Bunch Graph Matching (EBGM), and Active Appearance Model (AAM). Researcher’s observation is given below.

2.3.6.1. **Principal Component Analysis (PCA)**

PCA, often termed as the use of eigenfaces, the technique invented by Kirby and Sirivich in 1988. It requires the probe images with same size and normalized to align eyes and mouth shape. Each face can be thought of as a feature vector of eigenfaces and is compared with gallery images by calculating the distance between their respective feature vectors. PCA algorithm was is the basis of numerous studies in psychological studies. In the given image sets representing s-dimensional vector algorithm finds t-dimensional subspace which corresponds to maximum variance direction in the original image space. This new subspace is normally lower dimensional (t<<s). If the image elements are considered as random variables, the PCA basis vectors are defined as eigenvectors of the scatter matrix.


2.3.6.2. **Linear Discriminant Analysis (LDA)**

The LDA algorithm whereby two or more stimuli are distinguished is based on the vectors in the underlying space that separates sample classes. For all samples of all classes the between-class scatter matrix (SB) and corresponding within-class scatter matrix (SW) are defined. The class separation matrix and a measure of separability are calculated. After maximizing SB while minimizing SW, which maximizes the ratio \( \frac{\det|SB|}{\det|SW|} \). To calculate eigenvectors ratio is maximized from the column
vectors of the projection matrix. This yields \((SW^{-1} \times SB)\) eigenvectors which is used for comparison and obtaining results.

Ref: Discriminant analysis for recognition of human face images by Kamran Etemad and Rama Chellappa, University of Maryland, 1997

2.3.6.3. **Elastic Bunch Graph Matching (EBGM)**

In EGBM most of the variance is extracted as face description. It is represented as image graphs, with nodes positioned at fiducial points for various facial features and edges labeled with 2-D distance vectors. Each node contains set of many complex wavelet coefficients at different scales, varying in phase and amplitude. They are named as "jets". Recognition is based on comparison of image graphs. A labeled graph representing set of nodes is connected by edges, nodes are labeled with jets, and edges are labeled with distances.

Ref: Face Recognition by Elastic Bunch Graph Matching by Laurenz Wiskott, Jean-Marc Fellous, Norbert Kruger and Christoph von der Malsburg, Institute for Neural Computation, Ruhr-University Bochum, Germany and University of Southern California, CA ,USA, 1999,pp. 355-396

2.3.6.4. **Active Appearance Models (AAM)**

An Active Appearance Model (AAM) is an integrated statistical model which combines a model of shape variation with a model of the appearance variations in a shape-normalized frame. An AAM usually built during training phase contains a statistical model if the shape and gray-level appearance of the object of interest which can generalize to almost any valid example. Starting approximation holds the key for all processing sets. Matching to an image involves finding model parameters which minimize the difference between the image and a synthesized model example projected into the image. Although it is good for motion tracking, it is very difficult to handle some sets such as occlusions, extremely flexible objects.
Facial recognition technology has emerged in a great way as it can be automated to cater contemporary verification and identification. There is huge market waiting for a robust, fast and effective facial recognition system. Apart from rigorous development, performance evaluation issues it will have to address many challenges and concerns.

- **Performance:**

  The performance is marked on the basis of the types of tasks it can successfully perform under any given conditions its known limitations.

- **Evaluation:**

  Every system is evaluated based on the quality and variety of generated reports. In this task evaluation procedures are very important that are used to produce more useful and transparent results.

After evaluating and reviewing various facial detection/recognition algorithms, it brought to notice that the main aim of facial detection/identification/recognition differ from the facial reconstruction system. Facial detection/recognition system works only if the facial data is already at place but facial reconstruction system works to generate facial model, at times with unknown end results. Although it is generally stated that reconstructed facial model should resemble with the source face, facial reconstruction system may not be build that support a specific facial detection algorithm. For the same reason Researcher decided not to support any facial detection/identification/recognition algorithm with facial reconstruction system.
2.4. **Industrial Applications**

There are many industrial applications already dedicated various approaches listed in chapter 2.1.3. These industrial applications are integrated solutions that cater need of single or multiple fields. Researcher will not be considering all of them but some of them are closely related with the phases of the proposed 3D Facial Reconstruction System. The review of such industrial solutions helped researcher to decide various required features that should be imbibed in the proposed system.

2.4.1. **Entertainment Industry (Facial Modeling/ Simulation)**

2.4.1.1. **Eymatic FaceStation**

http://www.eymatic.com

Fig.2.67 Screen Shot of FaceStation 2 software

FaceStation 2 was released in 2002 but now it is closed. FaceStation 2 integrates Eyematic's patented computer vision technology with speech analysis techniques to dramatically improve the realism and accuracy of the resulting facial animation. This integration also simplifies the creation of high-quality multiple language content and sound-based animation effects. FaceStation2 includes additional professionally designed, ready-to-animate characters as well as workflow and usability improvements.
The product is good for animation but does not support dimension driven models. The proposed facial reconstruction system also supports facial variations with added advantage of dimension driven modification tools.

2.4.1.2. FaceGen

http://www.facegen.com

Fig. 2.68 Screen Shot of FaceGen Modeler 3.4.1 software

Application can be used to create realistic human faces in 3D either from photos or from scratch. Edit faces with over 150 controls including age, race, gender and click-and-drag editing. It is based on tween-two-faces design.

The software offers 3 step process to create realistic faces in following steps: 1. 3D human faces from 1 or 2 photographs or at random. 2. Adjust age, race, gender and 150 other controls and 3. Apply faces to any polygonal mesh and UV map. Even if the software cannot create exactly the head you have envisioned. For example, getting the bulbous nose I envisioned for a character proved impossible just using FaceGen, but FaceGen gives a workable 3D facial model. FaceGen delivers good Caucasian/ Negroid facial model which does not relate Indian facial features. FaceGen does not support anthropometric dimensions where as proposed system supports anthropometric dimensions and dedicated for Indian population.
2.4.1.3. **Poser**

http://my.smithmicro.com/mac/poser/index.html

Fig 2.69 Screen Shot of Poser 8 software

Digital content creators such as 3-D artists use Poser to set up and animate human characters, animals, and props. Poser has never been exclusively a modeling program: It is very difficult to create 3-D models from scratch, but rather, the software easily allows users to create complete scenes with existing 3-D geometry. Poser can give face kaleidoscope, means huge permutations to play but requires lot of manual tweaking to generate a special face. It does not support skull and facial reconstruction features. The proposed system will have face kaleidoscope with reconstruction features. It will help user to build a specific face as well as designing unknown/unseen face.

2.4.1.4. **Famous3D ProFace**

http://www.famous3d.com/
It was facial modeling software with anatomically based tools. Currently support is discontinued. The proposed system have Vyaktirekha concept that supports facial landmark based modification system.

2.4.1.5. CrazyTalk

http://www.reallusion.com/crazytalk/

Fig. 2.71 Screen Shot of CrazyTalk software
Reallusion - CrazyTalk transforms image into an actor and using facial fitting technique, it generates natural life-like head movement. The real labor comes when you try to make the face respond to the spoken word. There are algorithms to make the mouth movements needed for various phonemes, though these are quite basic, if you leave it to the program's own automation. It generated good model from photographs but fails to deliver dimension driven model.

2.4.1.6. LifeStudio_Head


LS: HEAD is a face modeling and animation package with a large library of assets. Its key features are Curve animation editing, “Macro Muscle” technology, Slider-driven feature amendments and 3DS max importer and exporter.

Fig. 2.72 Screen Shot of LIFESTUDIO: HEAD2.7 software

LifeStudio Head does not have support for anatomically and anthropometry based facial model.
2.4.1.7. **Di-O-Matic Facial Studio**


![Screen Shot of Di-O-Matic, Facial Studio software](image)

**Fig.2.73** Screen Shot of Di-O-Matic, Facial Studio software

Di-O-Matic Facial Studio offers features like Photo Matching to create heads based on photos or drawings. It has non linear approach for the head creation and deformation creation. User can deform everything from the eyes, the nose, the mouth, the jaw, the chin, the ears, the cheeks, the forehead, the eyebrows to the overall head shape including the teeth and the tongue. Facial Studio also offers facilities like skin texture editing, shading, and the facial muscles deformation.

There are many such types of software like Daz Studio, FaceShop pro, 3DMeNow develops 3D Human face for entertainment industry. Apart from that various 3D modeling softwares like Max, Maya, ZBrush, Softimage, Lightwave3D provides several tools for manual 3D modeling which can be used to develop 3D Human face. For the sake of simplicity and conciseness, researcher did not add the review of all the softwares in this section. Researcher found that still facial modeling is highly skilled, time consuming and manual task. Researcher analyzed various facial modeling products to determine common features and better approach for facial reconstruction system.
2.4.2. Medical Industry (Facial Visualization/Reconstruction)

2.4.2.1. Visible Human Project

http://vhp.med.umich.edu/index.html

![Fig.2.74 Visible Human Project by University of Michigan](image)

The University of Michigan Visible Human project visualizes human anatomy using detailed cross sectional images. It helps medical students, researchers, doctors as a reference human template with arbitrary cross sections, tool tips showing relevant medical information and helpful navigation tools.

Researcher found that there is huge gap in entertainment industry and medical industry. Even though goal of facial modeling is same but requirement, processing and results are completely different. There is a need of liaison or unifying approach with seamless information exchange and deliver required results.
2.4.2.2. **OnyxCeph (For orthodontists)**

http://www.onyx-ceph.de

![Fig.2.75 Screen Shot of Onyx Ceph 2D Pro module](image)

OnyxCeph helps orthodontists for planning, managing patient’s data. OnyxCeph interface enhances visual diagnostics by presenting deviations in mean cephalometric curves and patients profile curves. OnyxCeph has various image based tools to acquire patient’s data from digital cameras, x-ray units and other scanners. It helps manipulation like SQL database system, finally delivering output in visual format. OnyxCeph works only on photographs but cannot generate 3D model. Proposed facial reconstruction system will be able show critical orthodontic measurements of specific person from photographs and at the same time can generate 3D facial model of unknown person also.

2.4.2.3. **FaceFilter Studio**

http://www.reallusion.com/FaceFilter/

FaceFilter Studio’s 3D photo morphing technology that lets you import any portrait photo and enhance the facial feature either subtle to improve characters.
Unlike FaceFilter, proposed facial system can work on 3D input and deliver 3D model of an individual.

2.4.3. Police and Security System (Facial Identification/ Detection/ Reconstruction)

Fig.2.77 User Interface of typical Facial Reconstruction software
A crime lab computer shows the process of digital facial reconstruction, which provides a high level of speed, accuracy, and flexibility that is impossible to achieve in sculptures or hand drawings. Proposed system can be used by police department for generating 2D sketches or 3D models of criminals from given description.

2.4.4. Other (Predictions on the basis of Facial Features)

2.4.4.1. Digital Physiognomy

http://www.uniphiz.com/physiognomy.htm

Fig.2.78 Screen Shot of Digital Physiognomy software

Digital Physiognomy uses a sophisticated neural network to identify correlations between facial features and psychological characteristics using photo identification techniques recognized by law enforcement professionals. Only facial features that can be interpreted by physiognomy were used. You select eyes, eyebrows, foreheads, cheekbones, chins, noses, mouths and ears to assemble a face. Proposed system can be enhanced to generate 3D models of famous people. Proposed system can further enhanced by programs to give psychological characteristics based on established theory. Currently this topic lies out of scope of study.
2.5. Review of Related Research

2.5.1. Review of Facial Reconstruction Related Researches

Facial reconstruction process can also be called as facial approximation as it predicts the face based on the inputs and doesn’t guarantee the perfect match. It is the process of recreating the face of an unidentified individual through an amalgamation of artistry, forensic science, anthropology, osteology, and anatomy. The vast scope for various information inputs, wide variety of techniques and absence of standardized testing of results makes it more subjective. General strong belief is that skull is the detailed blueprint of the face. Among the various approaches most famous is forensic facial reconstruction. The technique is recreating face based on skull with the help of laying variable tissue layer and finally wrapping skin on it. In 19th century lie the roots of various Facial Reconstruction techniques. In 1989 French anthropologist Alphonse Bertillon demonstrated his method of determining identity through the measurement of specific features and body parts, which are unique to each person. Ref: Forensic Art, pg 10. With the advent of medical advances and collaborative scientific and artistic efforts added many dimensions to the field of facial reconstruction. Many forensic artists and practitioners found out various techniques with the help of forensic anthropology. Even though some of them have unproven independent technique still it claimed promising success. Many forensic experts have experimented and documented results which challenge others theories. Despite this controversy, facial reconstruction has yielded frequent successful results enough that research and methodological developments continue to be explored. Inadequate anthropological data, insufficient forensic data are the major reasons for the failure in predicting the perfect target face. The use of facial anthropology, forensic odontology knowledgebase makes an attempt to fill up the unknown gaps to reveal the facial topology.

3D Facial reconstruction is superset of facial proportion, facial modeling and to a little extent, facial detection. In the proposed thesis, Facial expression is not necessary and may mislead the objective to predict a target face.
The taxonomy of Facial Reconstruction Researches is shown in following figure.

Fig. 2.79 Taxonomy of various Facial Reconstruction Systems
Superimposition involves the process of making montage of available images of the subject and then its comparison with skull. The proper match of the superimposed image and the unidentified skull can be used as the successful use of technique even used as good evidence.

Forensic anthropologists concentrate on human biological characteristics at the population level, with special attention to uncovering the uniqueness that sets one individual apart from all others. This focus on isolating each human being as a unique entity is the essence of forensic anthropology. Study extracts will help us to build Jeevak system (Section 3.6.8) for reconstructing the faces of the dead.

2.5.1.1. 2D Facial Reconstruction

Forensic artists and forensic image experts are often the ones who create sketches or facial reconstructions, enhance photos or perform age progressions.

a. Image Modification

b. Image Construction

c. Composite Images

Fig.2.80 Composite drawing by Karen Taylor
As shown in fig. 2.80, a composite drawing based on a victim’s verbal description (left) and photo of subject identified (right), Forensic Art and Illustration, Pg. 4

![Composite Drawing Example](image)

Fig. 2.81 Example of Image Superimposition technique


Depending on input 2D facial reconstruction is done in 2 ways –

2.5.1.1.1. **Localize** (Individual features first and final outline of face)

As age progression plays major role in visualization, constructing facial features is based on old photograph or other concrete information. Widely practiced composite drawing approach can be thought of mix of both the processes. For an artist, Eyes may be of utmost importance.

The countenance is the portrait of the soul, and the eyes mark its intentions. ~Cicero

2.5.1.1.2. **Holistic**

(First face outline and then fit all features with relationship)
Researcher believes that restoration of human face in memory depends on the psychological distance. If target human face is well known or closely associated then that face is restored with more interrelated proportions and feature information tagged with emotional keys thus retained for longer term. In contrast, face without any prominent feature and emotion or incident tag may be erased quickly from memory by subconscious mind, eventually difficult to recall. Every individual has different style of remembering human faces and capability to communicate those faces. Gestalt principle of totality plays important role while drawing human face with holistic approach. Most vague and error prone input is verbal information. It all depends on the witness and information processing system to interpret and derive the facial model from given input. Main thrust is given on proportion and shapes, not on actual dimensions. Although it is widely practiced and proven approach for facial reconstruction, it has some inherent disadvantages.

i. Third dimension not considered - whole head in space and muscle thickness given least importance.

ii. Forensic Artist should have a understanding of cognitive psychology and behavioral science

iii. Interview techniques play an important role to extract information

2.5.1.2. **3D Facial Reconstruction**

2.5.1.2.1. **Tissue Depth Based**

In Tissue Depth based facial reconstruction, forensic artist glues depth markers onto skull landmarks of deceased persons to determine the average shape. Then Plasticine strips are used to join these markers. Finally facial features sculpted with great detail to give final real life look. Fig 2.82 shows typical tissue depth based facial reconstruction technique.
Fig. 2.82 Example of Facial Reconstruction using Tissue Depth technique


Researcher intends to use this technique in 3D environment to derive facial topology from skull. Researcher ideated Jeevak concept discussed in section 3.6.8 is based on the same philosophy.

2.5.1.2.2. FEM Based

Researcher has already discussed FEM based facial modeling in Section 2.3.4.5.

2.5.1.2.3. Scanned Range Data Based

Scanned ranged data based facial modeling is mentioned in Section 2.3.4.7.

3D Facial Modeling is superset of 2D sketching. Evidently 3D system has many advantages over 2D. Only disadvantage with 3D is that it is unable to isolate specific feature from entire face. Basically it works on holistic approach. Special programs can be written to implement localize approach in 3D which currently lies out of scope. Proposed system develops facial model in 3D environment so it also inherits all the pros and cons of 3D system.
Researcher would like to throw a light on few distinguishing factors of proposed system from existing solutions.

i. Most of the systems are restricted to work on some specific approach or technology which may turn into bane or boon with time and technology factor. Proposed philosophy is reinforced with concepts like Jeevak and Vyaktirekha (Section 3.6.8) to make design more flexible and dynamic. This makes proposed philosophy independent of specific technology and approach.

ii. Review of literature suggests that various fields require 3D human face but have different criteria. Presently there is no single solution which will deliver 3D face for medical and entertainment industry and police department at the same time. There is requirement of a flexible and adaptive liaison between these growing streams. Proposed methodology designed by Researcher is unifying approach that deals with translated inputs from different streams. Proposed facial reconstruction system can deliver same 3D facial surface for all these sectors conforming to their standards.

iii. As we have seen a few products were shut down, may be due to lack of understanding of future needs. Many face related streams are still evolving and many experts are documenting their findings. Most of the solutions available in industry do not deal with these technical innovations. In Proposed system Researcher stated methodology for reconstruction of Facial model in 3D environment that fits in current technological scenario, at the same time made room for future developments which is major advantage.

iv. Review of various paths and industry solutions revealed that medical industry solutions are highly expensive. Those products often require expensive scanning machines to capture data, expensive software programs and high end workstations for data processing. Proposed system is inexpensive solution that delivers required output with mere human input.
v. Entertainment industry requires human face models for 3D movies and games. Entertainment industry success stories are skill and experience dependent and often take long time to develop specific human face. Proposed system is very fast and does not require high level skills for processing.

vi. Most of the approaches work on specific type of input and thus inherently get attached with pros and cons and characteristics of input. Physically based systems are accurate but require intensive processing and thus only feasible when applied to special case. Proposed system imitates the physically based system with dynamic approach and does not require intensive data processing power.

vii. Anthropometry supplies various databases for human population but lacks in morphometrics analysis. Proposed system covers morphometric shapes along with anthropometric dimensions for all facial features.

viii. Although 3D scanning gives accurate results, the technology is quite expensive to use as mass input. Another disadvantage with 3D scan model is that it often delivers undesirable humongous information which requires immense amount of time and skill to refine and reuse for facial reconstruction. Proposed system is based on predefined AdarshMudra and not 3D cloud of points. Thus 3D scanned data is used only for tracing and not for building 3D facial surface.

ix. Photo based system can be cheap and widely appreciated but lack in dimension and may not generate correct topological modulation. Researcher identified that images should be calibrated and aligned properly before use. Researcher has given guidelines to use photo inputs and aligning technique to use as perfect input (Section 7.3). Proposed facial reconstruction system uses refined photographs along with some more information to validate inputs.
x. 2D composite facial reconstruction does not offer flexibility and largely depends on individual artist’s skill set. Proposed system can be used to generate 2D output with great flexibility.

xi. 3D sculpting is heavily used for facial reconstruction but depends on artistry of an individual to reflect inputs into believable facial model. Researcher confirmed that computer based 3D Facial modeling will eventually capture 3D facial reconstruction sector with its inherent strengths and has capability to deliver easy, efficient, skill independent, most scientifically accurate facial reconstruction system. Proposed system is designed with utmost care to reflect these qualities.

xii. Researcher also confirmed that forensic inferences should be independent of tools which will give various forensic experts the freedom to explore their visualizations. Proposed system does not restrict user to extract only one solution but allows multiple layered flexibility to test inferences by manipulating various parameters. So proposed system can also be viewed as kaleidoscope for forensic expert.

In gist, proposed system can be viewed as

1. fast facial modeling framework for modeler in entertainment industry

2. 3D face visualization tool for a forensic expert

3. intelligent 3D simulated facial surface for surgical planning

4. 3D head model with medical annotation showing rich content for medical student

5. quick sketching 3D canvas to generate face from explanation for police
6. It is fast, easy, robust and dynamic methodology which can be quickly adopted in any 3D environment. It is result oriented accurate system that can work with the help of any vague and/or accurate inputs and attempts to deliver competitive results confined to industry standards.