Chapter 1

Introduction

1.1 Animal Biometrics

Animal biometrics is an emerging field of computer vision, pattern recognition and cognitive science. It develops quantified approaches for recognizing, representing and detecting the visual phenotypic appearance of different species, individual animal, for analysis of behaviors, and morphological image characteristics [26].

The phenotype appearances of species depict the major composite of observable and discriminatory feature characteristics of an organism. The phenotype appearance includes the morphological characteristics, biochemical traits, physiological properties, phenology, behavior, and biometric characteristics for detection and representation of species or individual animal.

Animal biometrics operates at the intersection among of computer vision, pattern recognition, information sciences and ecology. It produces computerized systems for extraction of phenotypic features, measurement, better representation, and interpretations. In this chapter, a comprehensive description and overview of animal biometric based recognition systems along with its wide applications and highlight current and future developments are illustrated in detail.

The chapter starts by demonstrating proven designs and well-defined components of animal biometrics-based recognition systems to represent the phenotype appearances and visual discriminatory features of animals.

How these major components represent and compute the features and measure the quantity of biometric characteristics and morphological image pattern for detecting and representation features for identification of individual animal? How animal biometric based recognition systems can be used for detecting different species or individual animal, analysis of behaviors of species or individual animal?

Moreover, promising fields of wide spread applications are given in detail and point out major issues and challenges in the field of animal biometrics has demonstrated in this chapter. Finally, recommendations for advancing animal biometrics, development of accurate and robust animal biometric system and how non-experts can enter in this field are depicted.

1.1.1 Animal Biometrics: Fingerprints, Visual appearance, and Biometric characteristics

The field of animal biometrics generally exploits the various formal methodologies to represent and detect the visual features and phenotype appearances of different species. The formal feature represents based methodologies have been applied to identify and classify the massive classes of different species for identification of individual animal in the given class. It performs the detection of animal occurrence, or variation in the huge inter-individual and intra-individual classes of species.

The formal methodologies can also be applied for in depth analysis of individual behaviour and group behavior of animals, as well as to measure morphological image characteristics of animal body (*e.g.*, coat pattern of zebra, spot point on penguin's chest, and their evaluation of variation of inter-class (within-class (S_W)) or intra-individual (between-class (S_B)) changes over time. Because biometric data are implicitly associated with some properties such as intra-class variation and spatial variability. This poses a significant problem while designing animal biometrics-based recognition systems since these factors heavily affects the performance parameter.

The morphology of animal represents specific structural features of animal's body. It includes shape feature, structure, color, pattern, size to depict the aspects of the outward appearance of species, known as external morphology. For identification, animal biometrics utilizes both the variability and uniqueness of morphological image and biometric characteristics such as coat patterns for zebra, spot pattering based body structure (tiger), spot points on the chest of whale shark, vocalizations, movement dynamics, and body morphology of animal. Existing approaches in this discipline computationally interpret information about the appearance of animals in a systematic way (specifically through algorithmic formalization).

In particular, they define the classes of interest in a highly objective, comparable, and repeatable manner. Achieving this objective demands interdisciplinary research collaboration and better efforts between computer vision communities, ecologists, engineers, computer scientists, multidisciplinary researchers and statisticians. Animal biometrics expands on a longstanding, widely applied tradition in ecological and evolutionary studies of documenting and indexing appearance of species.

Animal biometrics-based recognition systems utilize physiological and behavioral biometric characteristics to identify the species and individual animal. The physiological characteristics are mainly face images, morphological image pattern, coat pattern, joint stripped configurations on coat pattern (for zebra), spot pattering based structures on chest of penguin, skin patterning behind the gills of each whale sharks, and muzzle point image pattern of cattle. The behavioral biometric characteristics presents the gait movement, roar, sound and walking pattern (movement pattern). These discriminatory body patterns can be shown in the form of visual feature of species and its nature, which forms the textual pattern on the body surface of animals. In the massive diversity of different species, such prominent visual marking are known as coat patterns or morphological image pattern.

The morphological image patterns frequently appear on major body surface in the form of colorization of furs, feathers, scales, surface, and cuticle of different species or individual animals. These discriminatory patterns have been repeatedly recognized as 'smart' visual markers-based unique designs or immutable pattern that can boost the likelihood of a species survival. The various examples of visual marking patterns are eye-spot pattern on the wings of butterfly, colored ring based visual marking points on snake's body, joint stripes in the coat pattern on zebra's body, spot points and dots or color pattern on cheetah and tigers. Figure (1.1) illustrates a small selection of coat patterns from different species.

In general, discriminatory patterns of various animals differ significantly from individual to individual while following a wider theme general for a species where the variance of between-class and within-class of species caters prominent and valuable features to discriminate the class of species or individual animals.

The significant differences in biometric features are concentrated in the few part of the body surface of the animal. These features, such as joint stripes in the coat pattern of zebra, spot patterning on the chest of African penguins, spot point configuration of the whale shark, and dense pattern of muzzle point image of cattle are the proper biometric pattern that presents unique features or combination of permanent features. These features

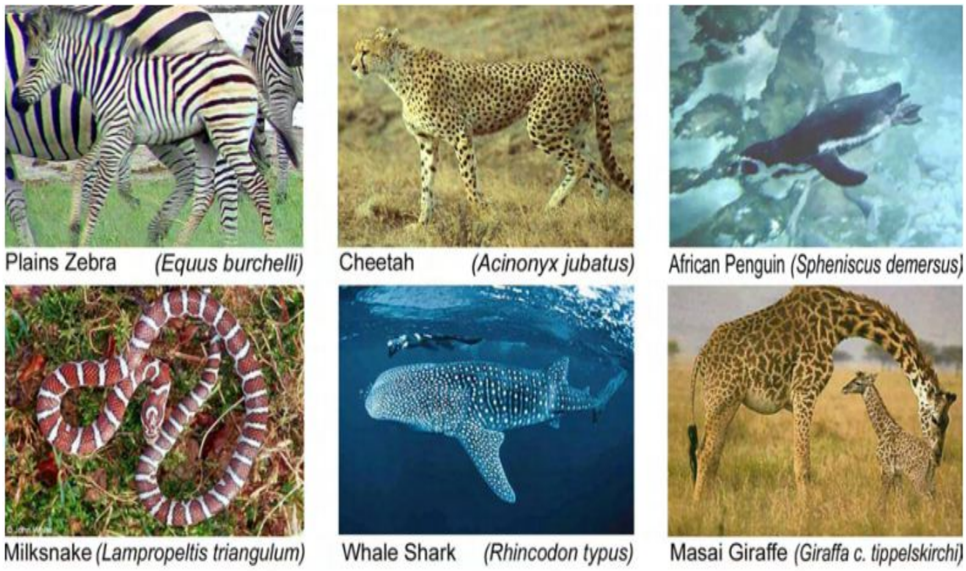

FIGURE 1.1: Illustrates the coat pattern structure of different species. The images present six different species which is visually adapted to their habitats by developing body patterns that effectively camouflage within their environment or group of similar species (conspecies).

are more appropriate and accurate biometric identifiers to characterized and recognition of the individual species or animals.

1.1.2 Interdisciplinary Relevance: Animal Biometrics

Currently, multidisciplinary researchers study large populations about different kinds of animals or species based on various source information. The information about individual animal was captured from different sighting, or sources, they always applied the methods of sampling and analysis known as capture-mark-recapture. The capture-mark-recapture relies on the availability of the approximately vast collection of extensive data regarding repeated sighting or capture of same individual or group of animals.

Multidisciplinary researchers employ visible color or unique identification number based on the ear-tagging system, paint or dye, embedded of passive integrated transponder and microchips as different markers for identification of individual animal. The marking method has been precious for the understanding of population changes, identification, tracking and monitoring of individual animal and species;yet these systems are invasive. Species or individual animal that carry ear-tags, embedding microchips and other appliances may be detrimentally affected. Markers might loosen, lost quickly and wear out affecting study results and possibly wrecking members of species under observation.

Also, the false marking-based approaches mentioned above comprise significant technical-economic drawback: (1) the reading of visible marking ear-tags normally requires manual reading on a large scale, while radio or satellite-based monitoring frameworks and tags are very costly up to $10,000 per device. Biological and multidisciplinary researchers, therefore, desire non-invasive, easy to use, acquisition, relatively cheap means to identify species as well as individual animals intimates that operated fast and robustly under field conditions and on large populations.

1.1.3 Advantages of Animal Biometrics

Several discriminatory features of animal biometrics and their valuable output make them promising and potentially powerful tools for studies of ecological, monitoring of animal individual animal, management and outbreak of critical diseases [26]. The quantification of biometric features contributes a genuinely objective measure for detecting, discriminating, and identifying species, individuals, and their behavior and morphology. The ability to do this independently of a human observer diminishes common sources of variation and bias in human observer studies caused by interpretation subjectivity, skill, or experience.

Automated processing facilitates, transparency of study results and standardization of methods for analysis. Standardized audiovisual data processing can be replicated probably for testing repeatable outcomes within and across studies, which is a basic requirement for a study to be considered scientifically rigorous. It facilitates comparisons of studies across individuals, populations, and species in a methodical and objective manner. Independent audiovisual recording devices can accumulate data continuously through time, compared with limited, discrete time periods of human observers [99].

Increased sample sizes may therefore be collected and processed. Furthermore, studies using well-established automated identification procedures may benefit from the ability to process data sets at considerably higher speeds compared with human observers, which is particularly relevant for tediously repetitive tasks [69].

Researcher performance degrades when conducting repetitive tasks requiring high accuracy for extended periods. Computers are better suited for this kind of data processing; thus, humans can concentrate on the more complex aspects of projects [99]. Freeing human resources for more complex tasks becomes increasingly relevant in budget limited and data-intensive studies [69].

The present dissertation exploits the naturally evolved, muzzle point image pattern of cattle to identify and verify of individual cattle based on their unique biometric features of muzzle point image patterns. By using animal biometrics, that is applying computer vision, pattern recognition, animal biometrics and image processing techniques to digital image of muzzle point pattern (nose pattern), it proposes and evaluates algorithms for automatic identification of individual cattle.

In this thesis, a novel animal biometrics-based recognition system is proposed for identification of individual cattle based on muzzle point image pattern and face image of livestock (especially cattle). The face image and muzzle point image pattern have been considered as primary and accurate animal biometric characteristics for the identification and verification of livestock animals (cattle). A cost-effective Cattle Recognition System (CRS) has been developed that will identify the cattle and improve the state-of-the-art based identification methodologies in the field of animal biometrics for animal recognition. The generality of the proposed approach is validated by achieving state-of-the-art accuracy on muzzle point pattern and face image database of cattle on different identification settings at the same time.

The remainder of the introduction on animal biometrics and cattle recognition based biometric characteristics is organized as follows: Section 1.2 illustrates the fundamentals of a cattle recognition system. The detail description about classical animal identification methodologies, for cattle identification based on face image and muzzle point image pattern, and how these biometric features of cattle are similar to recognition of minutiae points in the human fingerprint is demonstrated in Section 1.3. The motivation for selecting the muzzle point image pattern and face image of cattle as biometrics along with the major challenges are presented in Section 1.4. The objective of the thesis is given in Section 1.5. The major contributions of this research are outlined in Section 1.6. Finally, the organization of the remaining chapters of this thesis is given in Section 1.7.

1.2 Cattle Recognition System

Cattle recognition system is a pattern recognition based system [166]. The cattle recognition system consists of two phases: (1) training phase, and (2) testing phase. During the training phase, the recognition system creates a database to store the valuable information of cattle and their owner in the server of the proposed cattle recognition system.The stored owner information includes owner's name, date of birth (DOB), and address. The recognition system assigns a unique identification number to each cattle. In the testing phase, captured muzzle point as the query images (test images) are matched with stored muzzle point image database for the recognition of cattle. The similarity matching score is measured between the query image and stored templates using similarity matching based

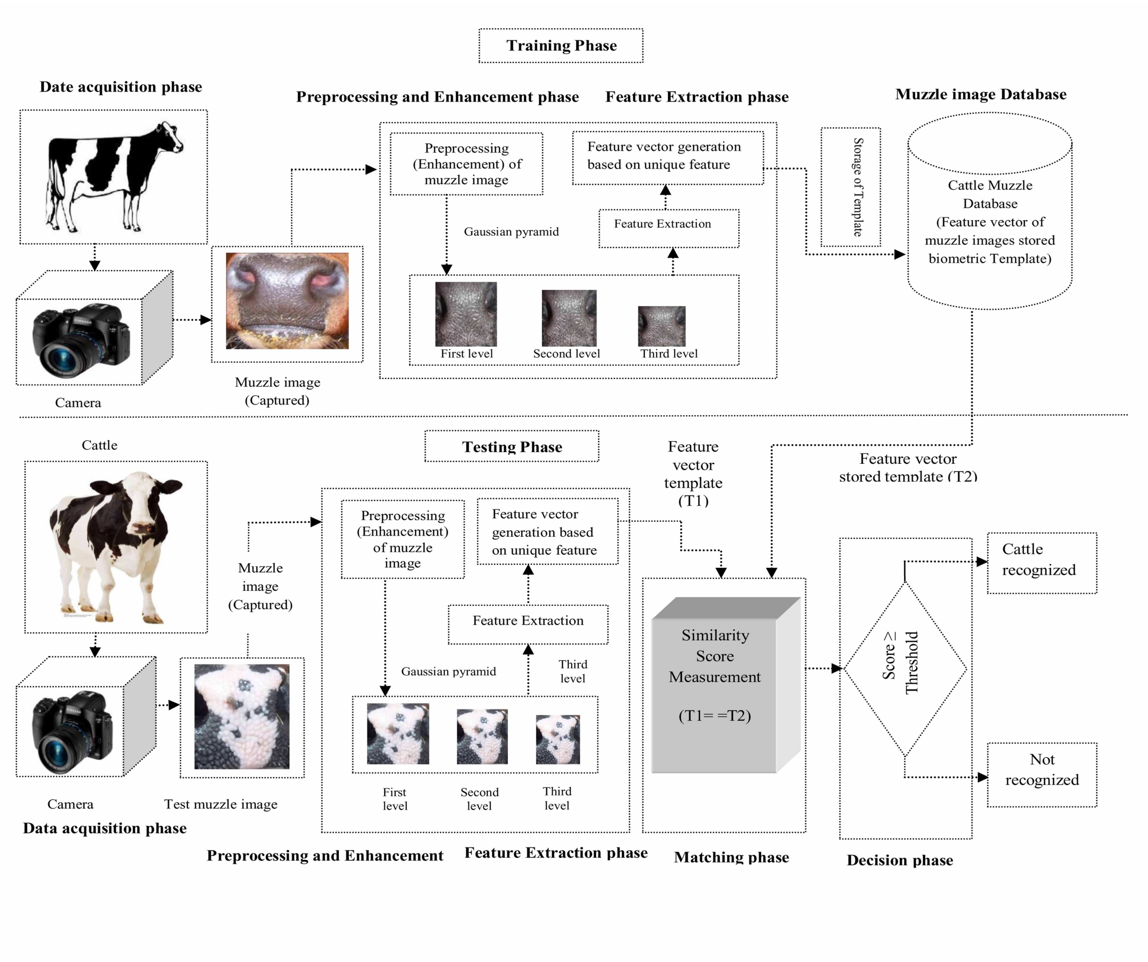

FIGURE 1.2: Illustrates the working of cattle recognition system for recognition of cattle.

techniques (*e.g.*, Euclidean distance, One-Shot Similarity (OSS) matching [196] and distance metric learning techniques [35]) and finally executes an action based on the achieved results of the comparison. The block diagram of cattle recognition system is shown in FIGURE (1.2).

With the obvious need for robust techniques for applications and uses, such as registration of massive number of livestock animals, monitoring and health assessment, to prevent the border crossing of non-registered animal and tracking of animals, animal biometrics has provided better detection and recognition approaches things that can be integrated into cattle recognition system for monitoring and registration of large-scale identity management systems. A cattle recognition system operates at the intersection between computer

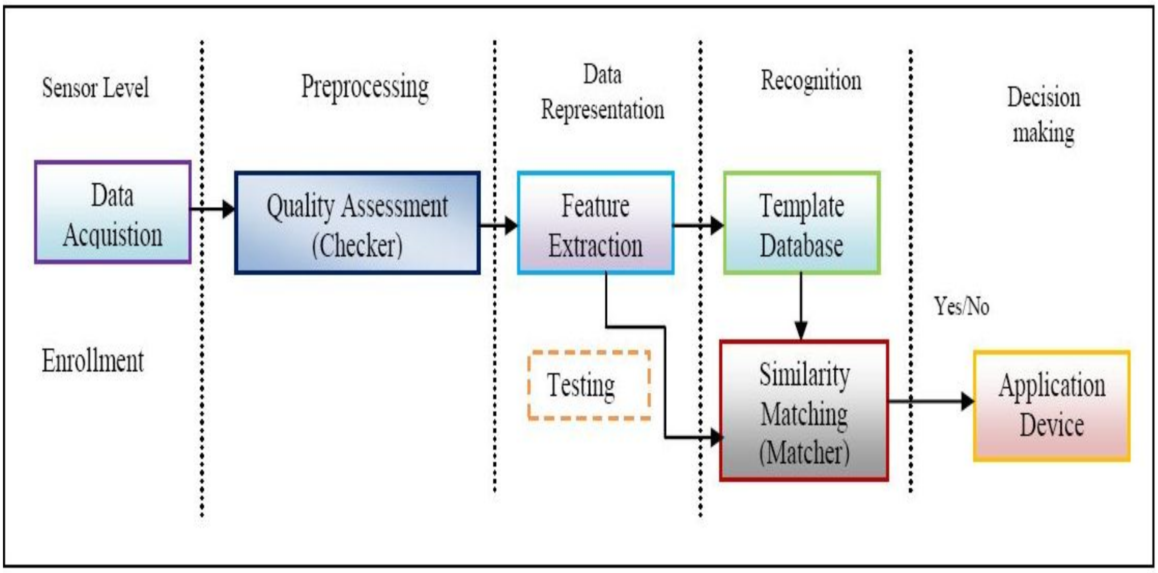

FIGURE 1.3: Illustrates the architecture of cattle recognition system

vision, pattern recognition, image processing, producing computerized systems for measurement and interpretation of physiological biometric features of the face image and muzzle point image pattern. The brief descriptions about component of cattle recognition system are given in the next subsection.

1.2.1 Major Component of Cattle Recognition System

Cattle recognition system consists of following components and operates in a five stage process (see FIGURE (1.3) for an illustration).

1. **Data acquisition:** Data acquisition stage includes sensors (*e.g.*, digital camera) for capturing the images of cattle and produce their feature representation for the processing of captured images of cattle.

2. **Data processing:** In this stage, the captured images are pre-processed and enhanced to perform the quality assessment and representation of captured muzzle point images of cattle. For the pre-processing, acquired image typically is applied for the

enhancement of data by applying image processing based enhancement algorithms in order to improve the quality of animal biometrics features.

The quality of the animal biometric data acquired by the sensor is first assessed in order to determine its suitability for further processing. Typically, the acquired data is subjected to a signal enhancement algorithm in order to improve its quality [99]. However, in some cases, the quality of the data may be so poor that the user is asked to present the biometric data again. The biometric data is then processed and a set of salient discriminatory features extracted to represent the underlying trait.

3. **Feature extraction and data representation:** It includes extraction of features from the captured images and prepared the compact representation of extracted features called a biometric template. The template is a unique mathematical code which consists of immutable biometric set of muzzle point and face feature of individual cattle. The generated templates are stored in the biometric template database.

4. **Matching:** The test (query) images of muzzle point of cattle are matched with the stored template in the database using Euclidean distance and distance metric based similarity matching techniques. A matching score is a measure of similarity or distance between two templates (*e.g.*, query template and stored templates) in the database. The generated matching scores from query features of subjects (cattle) are different during matching of cattle faces [166].

5. **Decision making:** Cattle recognition system then executes, whether the query template is matched or non-matched with the stored templates of muzzle point images.

   The match decision is usually taken based on a threshold value, and if the threshold value is greater than or equal to the similarity matching scores of given query muzzle point image. If the threshold value is above then threshold then identity of individual cattle is verified, otherwise rejected. Then matching of a pair of feature vectors is completed by applying minimum Euclidean distance based similarity matching technique for the generation of match scores, these similarity scores are used by support vector machine classification technique to classify and recognize individual cattle.

1.2.2 Performance Statistics

The central aspects to evaluate the performance of a biometric based recognition system is its accuracy from a user's prospective. An error of animal biometrics-based recognition system occurs either when the recognition system fails to cater the authentication about identity of registered subjects (animals). Moreover, errors also occurs when the recognition system fails to authenticate the identity of enrolled subjects, or when the system erroneously identify the identity of an impostor subject.

The major drawback of animal biometric system is related with the intra-class variation of captured biometric samples. More specifically speaking, two biometric samples achieved from a single subject but under different conditions differs considerably. This discrepancy occurs due to a variety of reasons including imperfect conditions. These conditions include sensor noises, low illumination in the features of individual physiological and behavioral characteristics, ambient conditions (*e.g.* , temperature and humidity), and interaction of user with the sensors. The main objective of any recognition system is to incorporate some efficient mechanism for reducing the intra-class variations, while simultaneously increasing the inter-class (samples achieved from different subjects) variations.

In this thesis, primary animal biometric characteristics such as face image and, muzzle point image pattern of cattle are chosen and applied as discriminatory biometric identifier for recognition of individual cattle [69].

1.2.3 Operation Modes

A cattle recognition system works in two modes, namely *enrollment (registration)* and *identification*. In the enrollment phase, biometric features of cattle are captured from individual cattle using camera and stored in the cattle database. On the other hand, captured images of cattle are matched based on extracted features to compute the similarity scores for identification of individual cattle. The cattle recognition system is also applied for identification and verification of individual cattle. The identification and verification modes are illustrated in the next subsection.

1.2.3.1 Identification Mode

In the identification mode, a query (test) image is recognized by searching the entire template database for a match. It conducts one-to-many comparisons to establish the identity of individual cattle. In the identification system, the system establishes the identity of subjects (animals) (or fails if the subjects are not enrolled in the cattle image database) without the subject having to claim an identity.

The test sample is subsequently matched with all the samples stored in the database. A single match in between the samples is enough for the system to declare the animal or species as genuine. In certain implementation, the recognition system generates a list of identities of subject (cattle) from the stored database ordered according to their similarity matching score to the query image.

The biometric templates stored against the identities are then manually matched with the query to identify the actual match. The whole identification process is often known as a one-to-many search and is primarily used for identifying individual cattle.

The output of an identification operation is a sorted list of identities, ordered from the best match to the worst match. This kind of matching operation is also indicated as $(1:N)$ matching, with (N) being the size of the reference database. The identification operation can be either closed-set or open-set.

In closed-set identification, the identity of the input probe is known to be present in the reference database. However, in the open-set identification, the identity corresponding to the probe may or may not be in the reference database.

In identification mode, the captured biometric feature of an unknown individual animal is given to the recognition system. The system determines comparisons between the presented and stored set of biometric template based features available in the database. Based on comparisons, recognition system estimates the identity of an unknown individual animal from the extracted biometric features.

In closed-set identification the ordered score sets from the N probes are applied to evaluate the probability that the true matching identity concerning to a probe is observed within the top K (K $\leq$ N) ranks (*i.e.*, measure the right rate of identification with $t=0$). These probabilities are typically represented visually through the Cumulative Match Characteristic (CMC) curve [47].

1.2.3.2 Verification Mode

In verification mode, cattle recognition system authenticates an identity of individual cattle by comparing the captured biometric characteristics with the biometric template of cattle pre-stored in the system.

It conducts one-to-one comparisons to determine whether the querying user presents an identity claim along with the biometric sample. The system database is first searched based on the claimed identity of cattle. The biometric sample which is indexed corresponding to this identity is then extracted from the database and subsequently matched with the query sample. The recognition system declares a match if the matching scores are greater has a predefined threshold and indicates a non-match, otherwise.

1.2.4 Distributions of Match Score

A matching algorithm of the biometric system constitutes of two fundamental steps. In the first steps, an evaluation process assigns a similarity matching scores for the comparison. The similarity matching score is a value typically in the range $[0-1]$. A higher value of matching score represents more similarity between samples. The second step defines if the comparison is true or impostor by using a frontier threshold or decision threshold (θ). If the matching score is greater than the defined threshold (θ), the algorithm concludes it is a true comparison.

Alternatively, a matching process generating a matching score lower than decision threshold (θ) is considered as impostor attempt. Importantly, the decision threshold can be tuned by algorithm users to accomplish optimized results corresponding to some special settings.

Statistical techniques are applied to measure the confidence of that similarity matching techniques. Originally, it is tested on the extensive large set of comparisons for which the actual type (*e.g.*, genuine and impostor) is distinguished in advance. For each distinct values of match scores in the range $[0-1]$, the number of genuine and impostor comparisons that has been selected that match score value is estimated separately. Those quantitative are consequently plotted separately as two functions for genuine and impostor match score based distributions.

1.2.5 Measurement of System Errors

The score distribution function is applied for the analysis of similarity matching scores but not for algorithm error behavior. Accordingly, the cattle recognition system utilizes two principal commutative distribution functions for estimation and analysis of errors.

The effective of recognition system can be evaluated from performance it derives. The system performance is ordinarily measured regarding various computations of error rates. The error rates are mainly False Acceptance Rate (FAR) and False Rejection Rate (FRR).

- **False Matching Rate (FMR)/False Accept Rate:** False Matching Rate (FMR) measures the percentage of invalid inputs that are incorrectly accepted. Therefore, the recognition algorithms erroneously classify an actual impostor comparison as genuine. The FAR of a biometric system can, therefore, be defined as the fraction of impostor scores exceeding the threshold (θ).
- **False Non-Matching Rate (FNMR) / False Reject Rate (FRR):** This metric measures the percentage of valid inputs that are incorrectly rejected. Herein, the algorithm erroneously classifies an exact comparison as the impostor. A related metric to false reject rates is defined as **Genuine Accept Rate (GAR)**. The GAR is defined as shown in Equation(1.1):

$$GAR = 1 - FRR \tag{1.1}$$

  The Genuine Accept Rate (GAR) is the fraction of genuine scores exceeding the threshold (θ)

The performance measures of FAR and FRR functions for the authentication of subjects is shown in FIGURE (1.4). The comparison of performance measured-based scores are

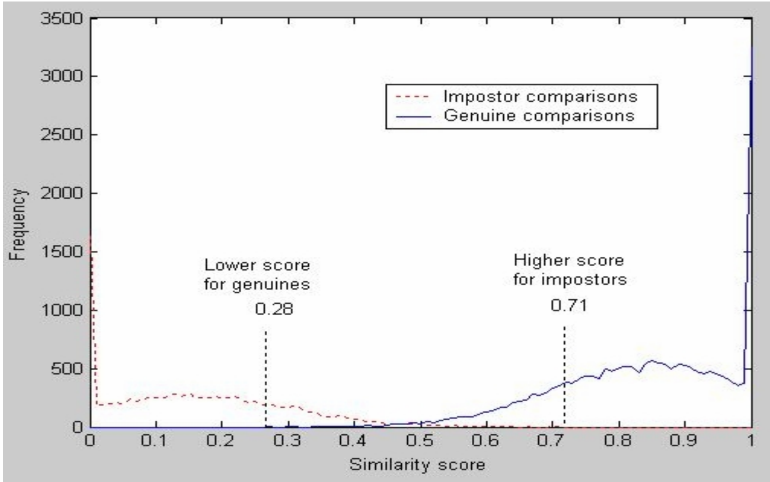

FIGURE 1.4: Illustrates the score distribution for real matching algorithm

illustrated on range [0, 1]. The genuine comparison based matching score value is distributed on range [0-0.4]. For authentication of genuine subject, the similarity matching score is equal to 0.28. While for the authentication of impostor subjects, similarity matching score value is 0.71.

Apart from FMR and FNMR, there are various other utility matrices for evaluation and visualizing the overall performance of cattle recognition systems. One of the most prestigious parameters for indicating the recognition based measure performance of the system is the Equal Error Rate (EER). An EER depicts the valve where FAR and FRR are equal to at certain threshold value. The EER is the single best description of the error rate of the cattle recognition systems; a low value of EER translates to lower error rates of the algorithm which is desirable and vice versa. The EER depicts an important but restricted set of the pair (FRR and FAR). For a more detailed analysis of system analysis, all the FAR and FRR combinations must be considered.

- **Receiver Operating Characteristics (ROC):** The Receiver Operating Characteristics (ROC) function is the best technique to illustrate the combined performance measures of FAR and FRR and its variations. In the ROC function, all the pairs of

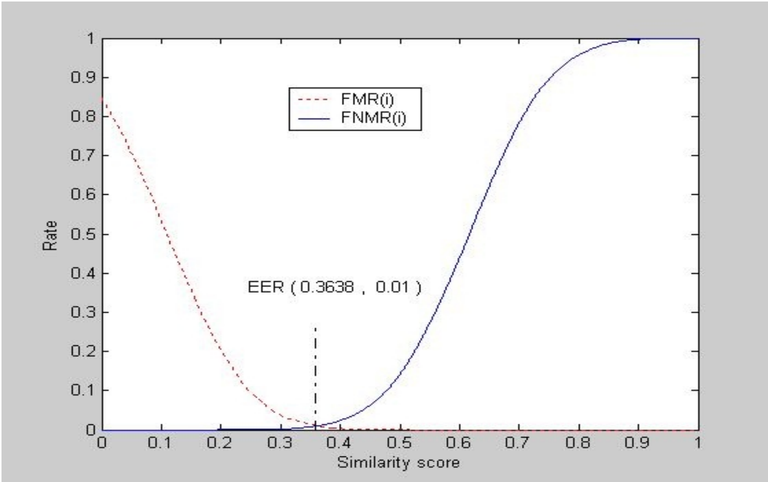

FIGURE 1.5: Illustrates the FMR and FNMR function distributions. For the match score 0.4, the FMR and FNMR are given respectively 0.3638 and 0.0239.

related values of FMR and GAR are plotted together without information about the match score values. Therefore, ROC functions present characterization of the trade-off between the two error rates. A sample ROC curve is depicted in FIGURE (1.5). The best possible performance of the cattle recognition system would give a point in the upper left corner or coordinate $(0, 1)$ of the ROC space. It consequently indicates zero incorrect matches (both genuine and impostor matches).

All of the errors discussed till now are induced due to the miss-classification of the recognition system process. However, there are different types of errors which are caused owing to other aspects of the system similar to sensors and human intervention. The most prominent examples of these circumstantial errors include the Failure To Capture (FTC) rate and the Failure To Enroll (FTE) rate. The FTC error indicates the percentages of times the cattle recognition samples is presented to it. This type of errors happens when the sensors are inadequate to locate a biometric signal of sufficient quality (poor quality).

Alternatively, Failure To Enroll (FTE) system error indicates the percentage of time the subjects are not able to enroll in the cattle recognition system. The FTE error occurs when the extracted features from the obtained raw biometric features of muzzle point image or face image are of extremely low quality. A high value of FTC and FTE errors usually intimates that there is some problem with either the input sensors or biometric subjects themselves. Nevertheless, great value for both these measured error rates also helps in preserve a high quality of stored biometric templates and consequently the overall system accuracy increases.

1.3 Classical Animal Identification Methodology

Cattle identification has recently played an influential role towards understanding disease trajectory, vaccination and production management, animal traceability, and assignment of animal ownership [9]. Cattle identification and tracking methodologies are dedicated to the process of accurately recognizing individual cattle and their products via a unique identifier or marking schemes [166].

In the available literature, classical animal identification and tracking methodologies are categorized into three group namely—(1) Permanent Identification Methodology (PIM), (2) Semi-permanent Identification Methodology (SIM), and (3) Temporary Identification Methodology (TIM) [9] [177].

The permanent identification method (PIM) includes ear-tattoos, the embodiment of microchips, ear-tips or notches, and freeze branding for the recognition of individual cattle. In the traditional cattle identification approaches, semi-permanent identification methodologies (SIM) are used to provide a required level of security to cattle/livestock by using ID-collar and ear-tags [10].

Moreover, the electrical signal based technique such as Radio Frequency based Identification (RFID) and sketch patterning (*e.g.*, paint/dye) based identification approaches are

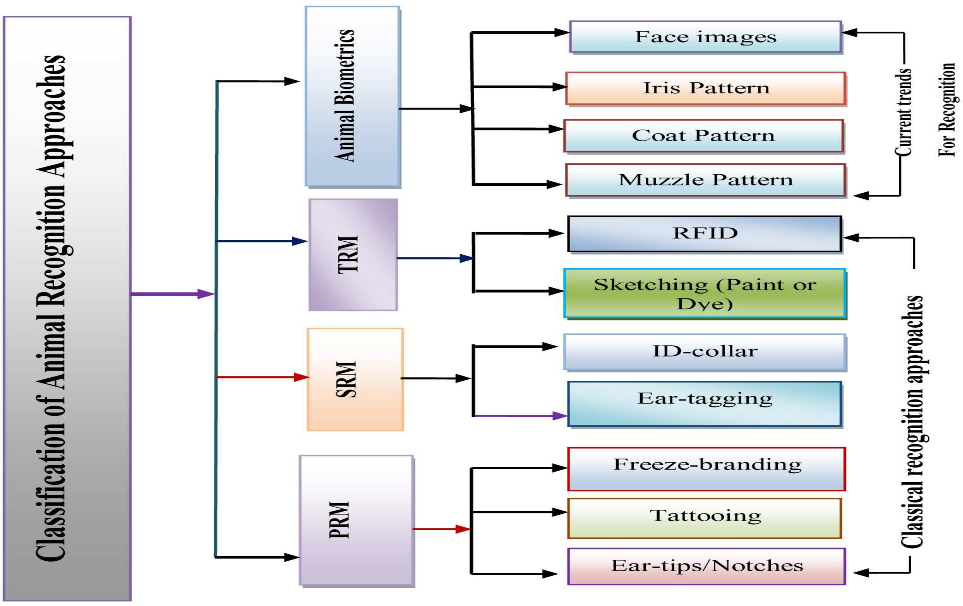

FIGURE 1.6: Illustrates the classification of classical animal recognition methodology

known as temporary identification methodology (TIM)[140]. The traditional methodology for cattle identification is shown in FIGURE (1.6).

The development of animal identification systems began at the end of the 1960s by multidisciplinary researchers, scientist and different research communities, while the first classical animal identification systems were applied only in 1976 for identification of animals [155].

The classical cattle identification systems such as ear notching, ear-tattooing, and freeze-branding, hot-iron, ear-tagging, and hoof marking have been applied for identification of cattle. These methods are not sufficiently reliable in identification and tracking of individual cattle because these are more susceptible to theft, fraud, and duplication of labeled ear-tags [104] [155]. Electrical identification methods, particularly RFID [152], emerged later than the classical animal identification methods and are characterized by higher reliability; however, they also present security, installation, and operational challenges.

Johnston et al. [95] and Wardrope [193] described in their research study that labels of ear tags of cattle can also be ultimately damaged and corrupted because of the long-term usages. The reliability of attached tag numbers (accuracy) have been major problems for cattle identification. Moreover, ear-tags are low-priced and usually easy to read the labels on ear-tags for the recognizing individual cattle.

The ear-tagging based techniques have been progressed in some ways for livestock identification. However, there is also being a limitation with ear-tagging based identification systems for recognition of beef cattle due to ear tags can be scratched from the cattle's ear. It disintegrates the ear of cattle in long-term usages. The ear-tagged labels have been lost if it is not applied properly to ear of individual cattle [32] [95] [193] . Therefore ear tagging techniques are unable to provide a sufficient level of security to cattle in traditional identification approaches.

Furthermore, sketched pattern on cattle's fur have also used to recognize the cattle based on the broken color of different breeds (*e.g.*, Ayrshires, Guernseys, and Holsteins) [140]. However, it required a skillful drawing ability of individual for coloring and sketched pattern process of cattle's body. The coloring process has always shown the lacks in the illustration of a standard quality (*e.g.*, high resolution) of sketched pattern; therefore, sketched pattern based method affects the representation and recognition of cattle based on these pattern images.

The sketch pattern based marking method is also applied for the identification of solid colored based pattern of different cattle breeds (*e.g.*, Redpoll, Milking Shorthorn and Brown Swiss breed) [141]. Therefore, traditional cattle identification methodology provides security to animals using invasive based techniques (*e.g.*, ear-tagging, freeze branding or notching). It also takes more cost for the development of artificial marking based techniques for the animal identification in the livestock management based framework [125].

The classical cattle identification methodologies such as ear-tags, freeze-branding, hot-iron, ear-tattooing, ear-tip or notches and electrical methods have long been in use; however, their performance is limited due to their vulnerability to losses, duplication, fraud, and security challenges [13] [15]. Therefore, these techniques are not able to cater a required level of safety to missed or swapped animals, verification of false insurance claims and reallocation at slaughterhouses of cattle [9] [15].

1.4 Motivation

Cattle identification and traceability are essential to control safety policies of livestock animals and management of food production. Many international organizations, (*e.g.*, food safety and monitoring of animal health), have formally recognized the significant values of the development of the animal registration and traceability systems using computer vision and pattern recognition techniques.

These organizations further actively encouraged for these recognition systems [189]. Such animal recognition based system include (a) controlling the widespread of the critical diseases of by identifying and detecting infected livestock animals, (b) decreasing losses of livestock yielder by controlling and outbreak of these diseases, and (c) reducing the government cost by the control, interruption, and eradication of the epidemic of critical diseases of animals [140].

In general the advantages of traceability are to recognize the ownership and parentage of each cattle, to identify the spread of disease so as to ensure food safety, and to validate sources, processes, productions, and exports [15]. The registration process would prevent efforts for cattle manipulation. However, identification of false insurance claims, registrations and tracking of individual cattle in the livestock monitoring based framework and classical animal identification systems are major problems [26].

Such major problems of animal identification cannot be ignored by scientists, experts, different research communities, and multidisciplinary to contribute valuable efforts for the design and development of robust, non-invasive and automatic recognition system for livestock animals (cattle)[156].

Beside that all of classical artificial marking based techniques generally can be duplicated or forged the embedded labels easily and in order to achieve registration and traceability of animals (especially for beef cattle [156]. Therefore, the need for a more robust cattle identification scheme has become desirable [26].

In order to achieve registration, traceability purposes, and identification of cattle, there is a requirement to develop a robust recognition system for identifying individual cattle based on their face image nad muzzle point features [9]. The major criterion for cattle recognition systems must be non-invasive, fraud-proof, a robust and suitable primary biometric marker characteristics, easy to acquire, cost-effective, accurate and also humane [126].

1.5 Objective of the Thesis

The objective of thesis is to design and develop a robust automatic recognition system for identification of individual cattle based on face images and muzzle point features of cattle.

A cattle recognition system has been proposed for validation of prepared face image database of for identification of cattle. The proposed system extract the features from the face images of cattle. The proposed recognition based framework also has been utilized to evaluate the experimental results of face image of cattle by using the existing handcrafted feature descriptor techniques and appearance-based feature extraction and representation techniques.

Moreover, the proposed cattle recognition based framework is also tested on the cattle face images using incremental machine learning approaches for better representation of extracted discriminatory features in the feature space. It is shown that experimental results derived from our proposed framework are found stable and correct for recognition of cattle.

An underlying intention of this thesis is to develop a cattle recognition system for recognition of individual cattle based on muzzle point features using hybrid texture feature extraction techniques for depth analysis of experimental results.

The proposed system extracts the muzzle point features of cattle from the muzzle point image database at different smoothed levels of Gaussian pyramid. The texture feature descriptors acquired at each Gaussian smoothed level are combined using fusion weighted sum rule technique. The proposed approach has shown the better performance accuracy as compared to the appearance-based face recognition and representation algorithms.

1.6 Major Contributions

The detailed contributions of this thesis are systemically stated below:

- A comprehensive literature survey of existing standard animal recognition methodologies for identification of cattle is presented. The survey conveys the state-of-the-art techniques for design and development of animal biometrics-based recognition system for recognition and verification of individual cattle based on muzzle point image pattern and face images as biometric characteristics.
- It also provides a survey of animal biometrics-based recognition system for species or individual animal using phenotypic appearance, biometric features, and morphological image pattern. The review work meticulously examines the techniques

and methodologies for the recognition of species and the current state-of-the-art approaches.

- Cattle recognition system is proposed based on muzzle point features for identification of individual cattle. The proposed novel framework has been developed using hybrid texture feature extraction and classification techniques to identify cattle. The hybrid texture feature extraction and representation methods characterize the extracted pattern based features of muzzle point images for better recognition and classification of cattle, as well as it examines discriminatory features using component analysis and supervised machine learning based multi-classifier techniques. The generality of the proposed approach is validated by achieving the current state of the art accuracy on muzzle point image database with standard identification settings.

- A hybrid deep learning based system for the recognition of cattle is proposed based on their muzzle point images. The proposed system applies a new convolution neural network, deep belief network based deep learning the framework for the extraction and representation of muzzle point features. In the proposed approach, stacked denoising autoencoder, an unsupervised feature learner technique has been applied for feature representation by reconstructing the output of the previous layer followed by distance metric learning via one-shot similarity with one class online support vector machine.

1.7 Thesis Organization

The rest of the thesis is organized as follows:

Chapter 2 presents a comprehensive survey of identification methodologies of the animal in the direction of animal recognition and tracking. The review work meticulously examines the classical methodology of animal identification based techniques. Seminal work employing these classical approaches are studied along with the evaluation of their strength and weakness.

Chapter 3 illustrates an overview of cattle recognition based on face image as biometric features of cattle. In this chapter, a cattle biometric-based recognition system has been proposed for the validation of prepared face image for recognition of cattle. For validation of framework, existing handcrafted feature descriptor technique and appearance based feature extraction and representation techniques are utilized. Moreover, the proposed cattle recognition based framework is also tested on the cattle face images using incremental machine learning approaches and better representation of extracted discriminatory features in the feature space. It is shown that experimental results derived from our proposed framework are found stable and correct for recognition of cattle.

Chapter 4 presents a novel framework has been developed using hybrid texture feature extraction and classification approaches to identify cattle based on muzzle point features. The hybrid texture feature extraction and representation methods characterize the extracted pattern of muzzle point image for better recognition and classification of cattle, as well as examines the discriminatory features of muzzle images using component analysis and supervised machine learning based multi-classifier techniques. The generality of the proposed approach is validated by achieving the current state of the art accuracy on muzzle point image database with standard identification settings.

Chapter 5 depicts a novel proposed recognition algorithm to extract the muzzle point features using handcrafted texture feature descriptor technique, such as speeded up robust features and local binary pattern for recognition of cattle. The proposed approach has been applied for the extraction of muzzle point features from cattle database at different smoothed levels of Gaussian pyramid. The texture feature descriptors acquired at each Gaussian smoothed level are combined using fusion weighted sum rule technique. Our proposed approach has shown the better performance accuracy as compared to the appearance-based algorithms for recognition and representation of cattle's face images.

Chapter 6 presents a hybrid deep learning based system for the recognition of cattle based on their muzzle point features. The proposed system applies a new convolution neural network, deep belief network based deep learning the framework for the extraction and representation of muzzle point features. In the proposed approach, stacked denoising autoencoder, an unsupervised feature learner technique has been applied for feature representation by reconstructing the output of the previous layer followed by distance metric learning via one-shot similarity with one class online support vector machine.

Chapter 7 concludes with the findings of this dissertation and draw potential suggestions for the future research.