Chapter 2

Related Work and State-of-the-Art

2.1 Animal Biometrics

Animal biometrics is an emerging research discipline in computer vision, pattern recognition, and cognitive science [99]. It is a promising research field that encourages new development of quantified algorithms and methodologies for representing, detection of visible features, phenotypic appearances of species, individuals and recognition of animals based on their morphological and biometric characteristics [26].

Furthermore, animal biometrics also assists the study of animal trajectory and behaviours analysis of the individual animal or species. Currently, real-world applications of animal biometrics-based recognition system have achieved more proliferation due to a variety of applications and uses, enhancement of quantity and quality of the collection of massive video, captured images of species, collection of ecological data and data processing. However, advance animal biometrics requires better integration of computer vision based methodologies and systems among the scientific disciplines, multidisciplinary researches, ecologists for studies of animal population [116]. Such valuable efforts will be worthwhile due to the enormous perspective of approaches rest with the formal abstraction of biometric characteristics, phenotype appearances, morphological pattern for building well-developed interfaces between different organizational levels of life.

Animal biometrics-based recognition system performs on the identification of species or individual animal using extracted features which is similar to recognition of minutiae points in human fingerprints [26] [99]. A feature is defined as a piece of information which is significant for solving the computational task related to a certain application. Moreover, animal biometrics can be applied to genuine understanding of feature representation of animals and classifying the phenotypic appearances of different species or animals based on feature representation of different species. It also identifies the location of the existence of our version with, a recognize the individual behavior as well as to distinguish the morphological image patterns or biometric characteristics of inter-class variation and intra-class of species or individual animal changes over the years [26] [99].

The bounding boxes around the animal's body illustrates the detection of body parts, their morphological pattern in the video or still images as are given input source (shown in FIGURE (2.1) [74] [151]. For a given image as input, features are extracted from images of captured species and extracted discriminatory features are classified to perform the identification of species or individual animal [26]. The face detection of apes, the configuration of unique marking of natural spot point patterns of whale shark for identification purpose [49], the frequency spectrum of head motion of tiger [79] and locomotion recognition [98] and histogram distribution of spot point pattern based configurations are shown in FIGURE (2.1) for identification of penguins.

The examples of four animal biometrics-based recognition systems are used for detecting and classifying species, individuals or behavior analysis (shown in FIGURE (2.1).It also depicts the bounding boxes which is highlight the detected body parts or morphological image pattern of interest in video or images.

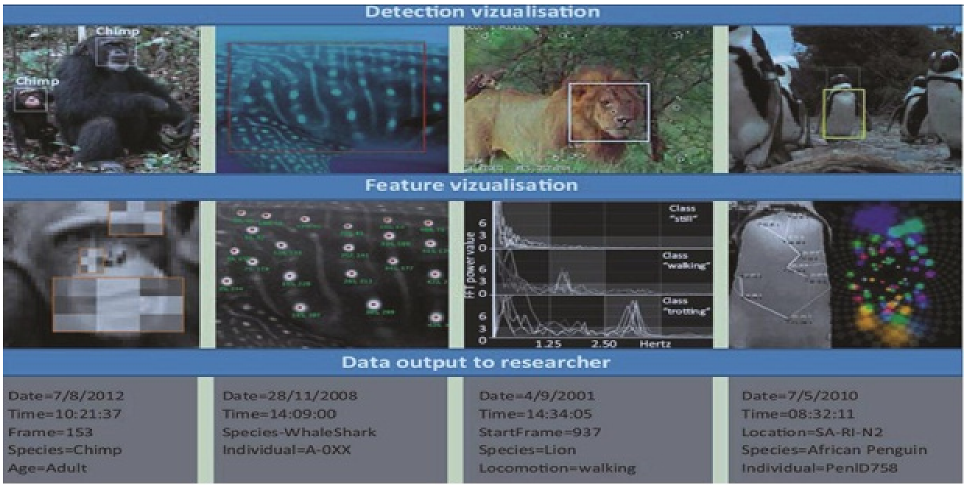

FIGURE 2.1: Illustrates the detection and classification of different species and individual animal using animal biometrics-based recognition system

Animal biometrics-based recognition systems use visual joint features for classification of animals. The recognition system includes structural features, spatial brightness changes and distribution, and gradient texture features (*e.g.*, detection of chimpanzee species) [59], configurations of spot point patterns (*e.g.*, for identification of individual whale shark) [49], spectrum of head motion (*e.g.*, recognition of lion locomotion) [79], and histograms of spot configurations (penguin identification) [165]. The brief description of the animal biometrics-based recognition system is presented in the subsequent sections.

2.1.1 Animal Biometrics Based Recognition System

Animal biometrics-based recognition system is a pattern recognition based system [99]. The recognition system is similar to SLOOP animal identification-based system [53]. The SLOOP identification system is also a pattern retrieval system for identification of species or animal based on their salient set of visual features. It retrieves the information (features) from morphological image pattern and biometric characteristics of species for the recognition of species and individual animal [53]. The SLOOP system uses the cloud computing, machine learning based techniques and crowd sourcing methods to greatly improve the identification accuracy of animals, and tracking movement and analysis of behaviors of animals [84].

Animal biometrics-based recognition system is basically a information retrieval system to extract the discriminatory features of phenotype appearances and visual generic features (*e.g.*, joint stripes of coat pattern of zebra [111], spot patterning on penguin's chest, spot points in the tiger body and shark whale [49] [84], and muzzle point image pattern of cattle [15] [131] [140]) for identification of individual animals or species.

A phenotype appearance is defined as visual features of species. It is a composition of recognizable characteristics of any organism [99]. These features include discriminatory information of morphological image patterns and biochemical or physiological [26] characteristics of species. The physiological characteristics generally include body structure, body shape, color information, coat patterns, size and specific structural features of organisms [26]. The brief description of the component of animal biometrics-based recognition system is discussed in the next subsection.

2.1.2 Component of Animal Biometrics-based Recognition System

Animal biometrics-based recognition system consists of following components-(1) sensors component (for acquisition of data), (2) detection of species based on captured image pattern, and extraction of feature from image pattern, and (3) storage capabilities, (4) similarity matching of query image of species with stored templates in the template database, (5) decision or action executed based on matching scores and defined threshold value, and (6) finally, utilization of extracting features characteristics by the interfacing of various applications or multidisciplinary users and researchers. The working of animal biometrics-based recognition system is shown in FIGURE (2.2).

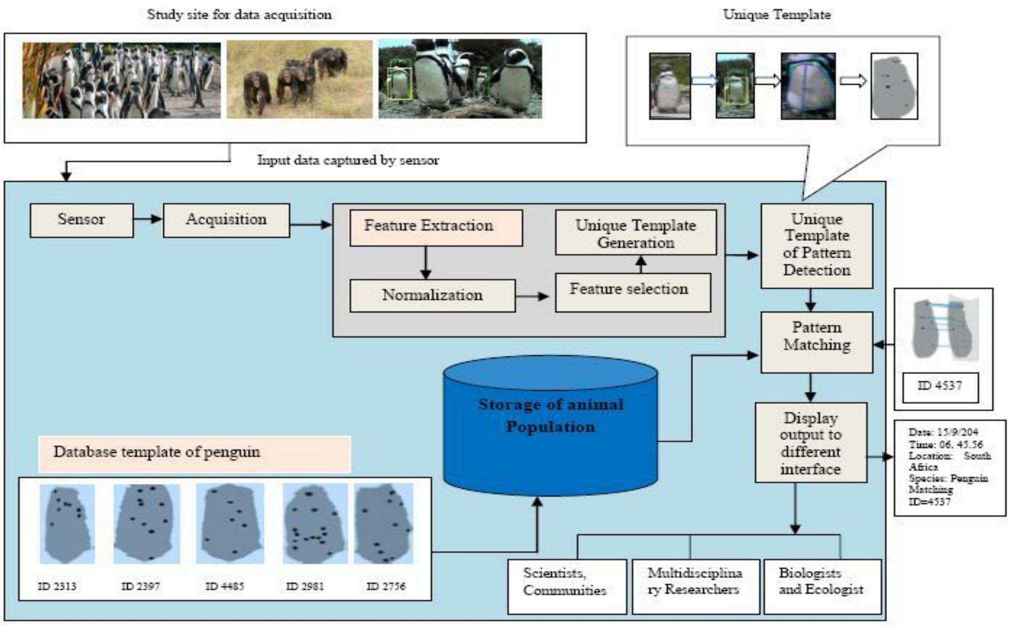

FIGURE 2.2: Illustrates the major components of animal biometrics-based recognition system

FIGURE 2.2 illustrates the relationship of different component of animal biometrics-based recognition system. The acquisition step depicts the capturing of input data from the various study site and data acquisition. The captured images are used for pre-processing of data and perform the measurements and interpretations of pre-processed data for the representation of animals. The animal systems is also applied to study of population and behavior analysis of individual animal by various multidisciplinary researchers, scientists, and engineers.

Each of the components of animal biometrics is illustrated to recognize the different species using different marking patterning based on spot point patterns for recognition of individual African penguin. The brief description of each component is given as follows:

2.1.3 Data Acquisition and Data Pre-processing

In the acquisition step, various sensors, such as camera (*e.g.*, surveillance camera, normal camera, trap camera) are used to capture data from the study sites in the data acquisition phase. After data acquisition phase, individual species are detected based on morphological image pattern and biometric features by applying computer vision and pattern recognition algorithms.

Animal biometrics-based recognition system extracts the biometric features (*e.g.*, the spot points on the chest of penguin) from the captured data (*e.g.*, video or image database). The extracted features are pre-processed and normalized for better representation of extracted features in the feature space. To reduce the noises and artifacts from captured database, recognition system uses the data pre-processing algorithm to process the captured images of species. The salient set of feature vectors are chosen to generate the unique templates from extracted biometric features and stored these templates in the database.

2.1.4 Extraction and Representation of Features

Representing and matching aspects of the features, such as phenotype appearances, morphological image pattern and biometric features in a quantifiable way is the central algorithmic challenge in animal biometrics [99]. The main difficulties are how to capture the discriminatory features using computer vision based approaches, pattern recognition technique, mathematical models and selected parameters: (1) animals are uncooperative in nature because, animals actively change their shape by pose due to head movement, (2) body surfaces of animal reflect differently under different lighting, and (3) animals frequently appear as partially hidden by other content (covering and non-covering problem), such as vegetation. Although computer vision based recognition techniques capture some of these aspects accurately, however, these techniques do not allow for an automatic association between them and input data images or video.

2.1.5 Matching of biometric Features

In matching process, the small representation of scientific data (*e.g.*, feature vectors) of each subject (animal) is matched. In the testing phase, a test (query) image of species or individual animal is matched with the stored template database and computes the matching scores using similarity matching techniques (Euclidean distance and distance metric learning based approach) for the identification of individual animal. The matching of biometrics pattern of species or individual is shown in FIGURE (2.2). The complete description of animal biometrics-based recognition system is diagrammatically illustrated in FIGURE (2.3).

Finally, interface component reports the consistent output of the animal biometrics-based recognition system to different users, such as scientists, multidisciplinary researchers, biologists and ecologists and software system for further study and analysis [99].

Based on available literature, the identification problems can be posed using animal biometrics-based recognition systems as follows: given a computer vision model and animal image, how can one decide the proper region of interest in the animal image that can be rendered by the utilized these model. Chosen area exhibits the region of interest to extract the discriminatory features and its representation of the animal body in the given images under which model parameterization occur (*e.g.*, what is the pose of the animal due to body dynamics and head movement etc.). Parametrization is the process of defining and determining the parameters required for a complete or significant specification of a model or representation of the geometric object.

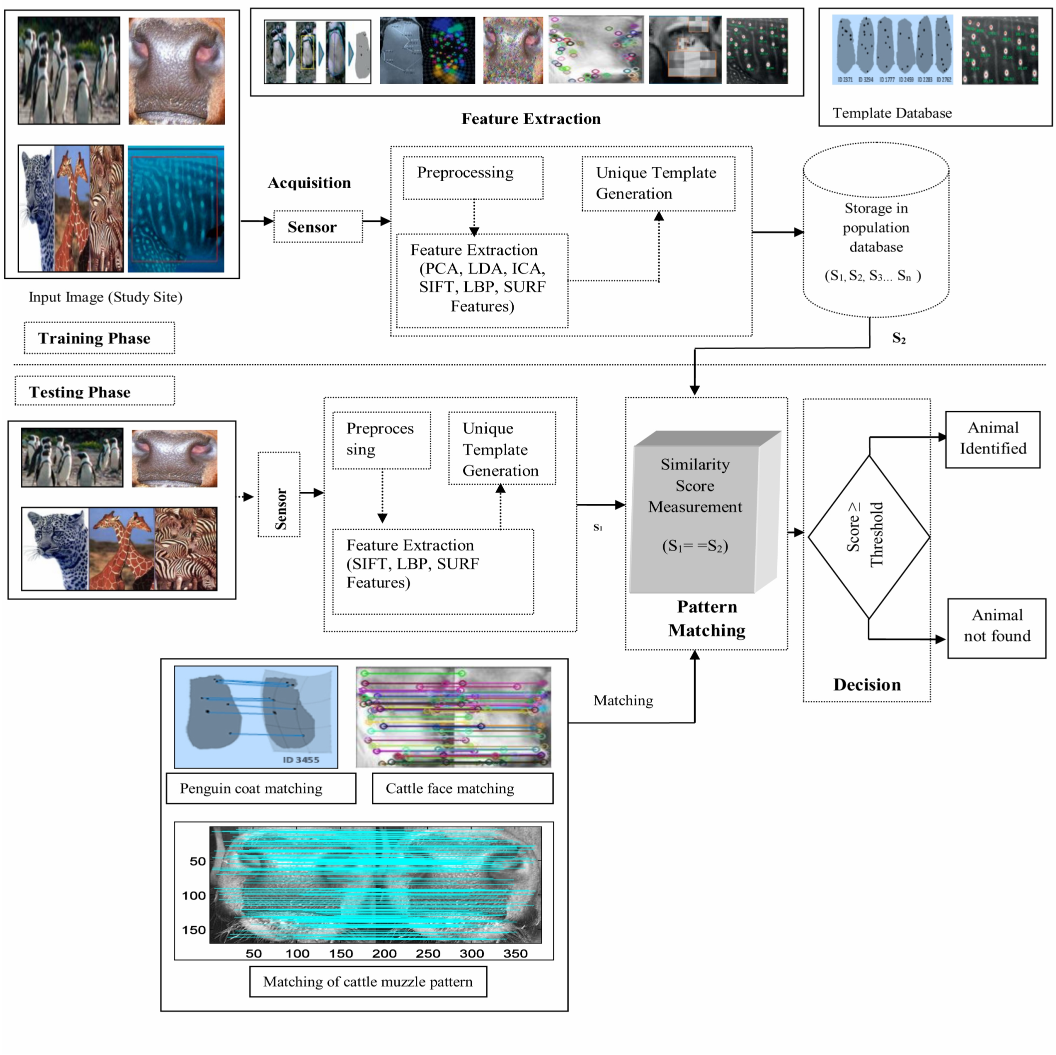

FIGURE 2.3: Illustrates animal biometrics-based recognition system with the major components

The computer vision and pattern recognition approaches have been used for the extraction and representation of visual features and biometric characteristics of species or individual for identification (shown in FIGURE (2.3). Based on the extracted features, these recognition approaches have been applied to perform the better analysis and recognition of species or animal for detecting and tracking individual animal populations across ecology.

Multidisciplinary researcher, biologists, research communities, and ecologists have started to apply the computer vision approaches for representation and detecting the visual features for identification of animals. They have customized the detection and representation of algorithms fundamentally. Therefore, ecological and evolutionary researchers have achieved and interpret the voluminous documentations, various photographic records and data of ecological field of different species across all populations. Current advances in algorithms for automated image-based recognition and tracking systems compromise the opportunities to remotely quantifying and recognizing the species or individual behavior at different scales.

In the field of computer vision, pattern recognition and image processing, multidisciplinary researchers have applied these techniques to solve the significant problems in animal biometrics. They have also addressed these major challenging problems of detection and recognition of species or individual animal by developing the efficient, innovative methods and computer vision based representation models. These models can be used for processing and classification of animal based on captured images efficiently and automatically.

In the available literature, identification of individual animal in the traditional livestock framework based systems, only traditional animal methodologies have been used for the identification of cattle for registration and traceability purposes. The classical cattle identification methodologies are demonstrated in the next subsection along with emphasizing their performance and major drawbacks.

2.2 Classical Cattle Identification Methodology

A significant factor in any accurate and efficient cattle identification and tracking system is gaining a measurable, collectable, distinguishing, inoffensive, and time-immutable identifier for each animal [15] [180]. Additionally, critical considerations for a secure animal identification system comprises the efficient, reliable, and accurate acquisition of information in a manner that precludes fraud and allows for easy data storage and retrieval [41]. In short, there is evidence of a huge requirement for a competent and efficient system of identifying individual cattle [126] .

Classical animal identification methodologies have extended deployments, long time utilization, and documented research investigations. On the other hand, modern biometric-based recognition methods require further research before large scale applications [140].

Classical cattle identification methodologies are categorized into following groups: Permanent Identification Methodology (PIM), (2) Semi-permanent Identification Methodology (SIM) and (3) Temporary Identification Methodology (TIM) [55] [166]. The major problems of classical animal methodology stem from their vulnerability to losses, deformations, and fraud, not to mention animal-welfare concerns [25] [85]. The brief description of classical animal identification approaches are illustrates in the next subsection.

2.2.1 Permanent Identification Methodology

The permanent identification methodologies generally include manual identification based marking schemes such as ear-tattoos, embodiment of microchips, ear-tips or notches, hot-iron, and freeze-branding for the identification of individual cattle. The complete description of permanent identification methodologies are given as follows:

- **Ear notching (EN):** It is a permanent identification method. It includes the process of mitigating a V-shaped section of the right and left ear of an livestock animal. The position of the ear-notch illustrates the identification of animal based on their labeled numbers. The ear-notching based approach exploits a combination of right-ear notching (litter number) and left-ear notching (animal's number) to uniquely recognizing individual animal. For example, an animal identified as $18-2$ is considered as the second animal in a group of 18. This animal would be marked by two notches each at the position 9 on the right ear and two notches at the position 1 on the left-ear. The outcomes of the ear- notching operation and the marking on the left ear and the right ear of animal are shown in FIGURE (2.4) [137].

Ear-notches (EN) based marking technique can distress a livestock animal, and such severe pain must be reduced via various methods regardless of the potential benefit to the animal or humans [139]. Ear notching is not scalable marking method. It can identify only a limited number of herd of cattle in the manual manner [137]. Therefore, ear-notches based marking technique is not a suitable for medium and large sized farms [115]. Ear-notches (EN) based marking technique is worth noting that these methods are also employed for identification of goats, sheep and pigs [55]. The marking of beef animal using ear-notching technique is shown in FIGURE (2.4).

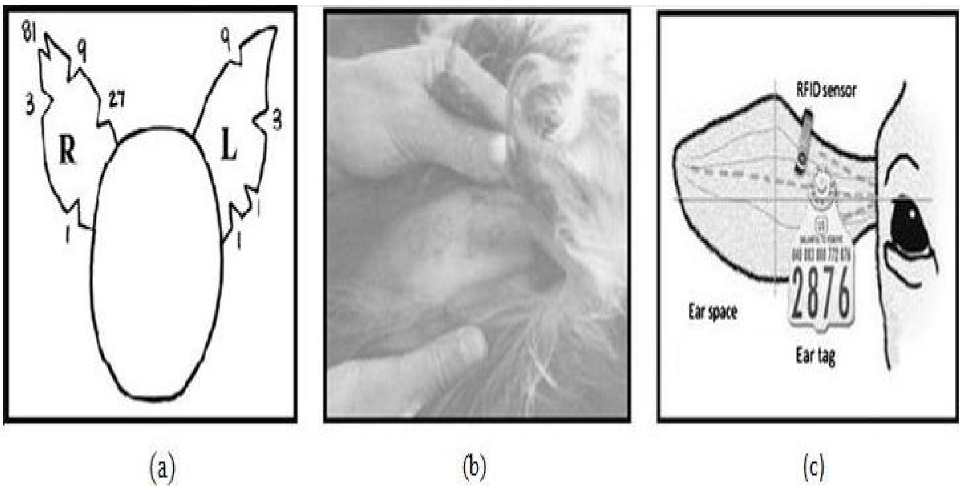

FIGURE 2.4: Illustrates the classical identification methods for beef animal: (a) ear-notching, (b) ear-tattooing, and (c) ear-tagging with Radio Frequency Identification (RFID) sensor.

- **Ear tattooing:** Ear tattooing based marking technique is a classical animal identification methodology. It is widely used for identification of different animals [146].

  The ear tattooing based marking technique uses the letters, numbers, or a combination of letters and numbers. A special ear tattoo pliers has been used to place ear tattoo holes inside the animal's ear, and then an indelible ink is decanted into the holes, where it is trapped under the skin's surface and shows up as letters or numbers [55]. The marking of cattle using ear tattooing is shown in FIGURE (2.4).

  The major advantages of ear tattoos based marking approaches are (1) it avoids the problem of distress to the animal, however, it is highly susceptible to alteration, duplication, removal and fading of colored ink of marked tattoos. In addition, ear tattooing based identification schemes has limited scalability for cattle identification. The ear-tattoos based identification is a time-consuming, and laborious operation for marking the ear of livestock animal and individual cattle. It is always needed to check, read, and record tattoos for identification of individual cattle in real-time scenario.

- **Hot-iron branding:** Hot-iron branding based marking scheme is another permanent identification method for identification and tracking of the individual animal in the herd. It uses a farm's brand, letters or unique numbers which are impacted on the body of the animal to recognizing different animals visually.

  The hot-brand bearing identifier is heated to a suitable temperature, firmly impacted on the body surface of the animal, and removed the hot impacts immediately. This is a invasive approach for identification of individual cattle. The invasive method performs the marking with particular care to the temperature of the branding tool [55]. Hot iron branding seems to be a simple identification process. The major drawbacks of this approach are-(1) it provides low identification accuracy, (2) the marked symbol can be easily duplicated, removed, or altered, (3) hot iron branding based marking is invasive technique. Therefore, it is not better for animal identification. The hot-iron based marking technique is prohibited in the U.K. due to animal welfare concerns [171]. The hot iron branding method is used for identifying an animal's ownership rather than of the animal's identity, which is not useful for future monitoring and tracking processes.

- **Freeze branding:** Freeze branding is permanent identification approach. It was initially used by Dr. Keith Farrell of Pullman, Washington for identification of animals in Sweden around 1966. Freeze branding based marking scheme works differently to the hot-iron based branding method. It totally depends on destroying the natural pigment in the hair of the animal. This procedure produces white hair growth in the area of skin the hot iron impacted or touches [55]. The freeze branding based marking and identification method are very simple for marking the individual animal for identification purpose. The major shortcomings of this approach are: (1) it can not be performed for marking to white animals, (2) it is invasive based identification technique.

  Also, such freeze brands can be obscured by changing the white color of the brand to blend with the animal's original color. It takes more time to do accurately than hot-iron based technique and requires a lot of specialized equipment. The freeze-branding based marking scheme has performed for identification of ownership or parentage of the animal. However, some states have considered it as the proper marking technique for identification of animals.

2.2.2 Semi-permanent Identification Methodology

In the classical cattle identification approaches, Semi-permanent Identification Methodologies (SIM) are used to provide a required level of security to livestock animals by using

ID-collar and ear-tags based identification techniques [109]. The brief description of the SIM based approaches for animal identification is discussed as follows:

- **Collar:** An animal collar based identification is a semi-permanent identification approach. In collar based identification system, collar devices are attached to the neck of the animal or cattle to allow it to be harnessed, tied up or for various other reasons. A unique identification number is embedded in a piece of material. The embedded numbers are frequently placed on collars for controlling and tracing of the animal.

  Similarly, collar based identification systems are also utilized for monitoring and tracking of non-pet animals throughout the world. The collar based identification systems can also be used to zoo animals and domestic animals including cattle or calves, goats, and sheep, etc. Pet collars can be formed of leather, nylon or metal. Metal collars are used for larger and dangerous dogs. They can come with traditional or quick-release buckles. Collars are applied for fashion purposes. Pet collars also include collars primarily designed for raccoons, ferrets, and other such pet animals.

  The major shortcoming of collar based identification approach is that it can be dangerous for pets that live in crates or which might get stuck in tree branches and that is why safety collars have been developed. Breakaway collars are specially designed to prevent the pet from choking or getting stuck because of their collar.

- **Ear tagging method:** Ear tagging method is one of the most widely accepted identification system for livestock animals. It provides convenient and low-cost identification of individual cattle. It overcomes some problems associated with conventional methods, such as distress to the animal and difficulties about the visual inspection by humans [12].

Ear tags can be constructed from metal or plastic components and can be labeled with bar codes, numbers, or colors. They may even carry wireless chips for electrical identification systems. The design considerations of any ear tag should render the item tamper-proof and visually legible, and the tags should remain attached without harming the animal [171]. Figure 2.4 (c) presents an example of marking of an animal using ear-tag based technique for identification purpose [80].

The ear tagging techniques have been progressed for cattle identification in some ways. 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 and it disintegrates the ear of cattle in the long term usage. The ear tagged labels have been lost if it is not applied correctly to cattle's ear [166].

Johnston et al. [95] and Wardrope [193] reported in their research study that label of ear tags can also be eventually damaged and corrupted because of the long-term usage and its low reliability and recognition rate (accuracy) have been major problems for cattle identification. Therefore ear tagging techniques are not able to provide a competent level of security to the animal in traditional cattle identification approaches.

2.2.3 Temporary Identification Methodology

The electric signal based technique such as Radio Frequency based Identification (RFID) and sketch pattering (*e.g.,* pain/dye) based identification approaches are known as temporary identification methods(TIM) [9] [70]. The detail description of the temporary identification methodology for animal identification is given as follows:

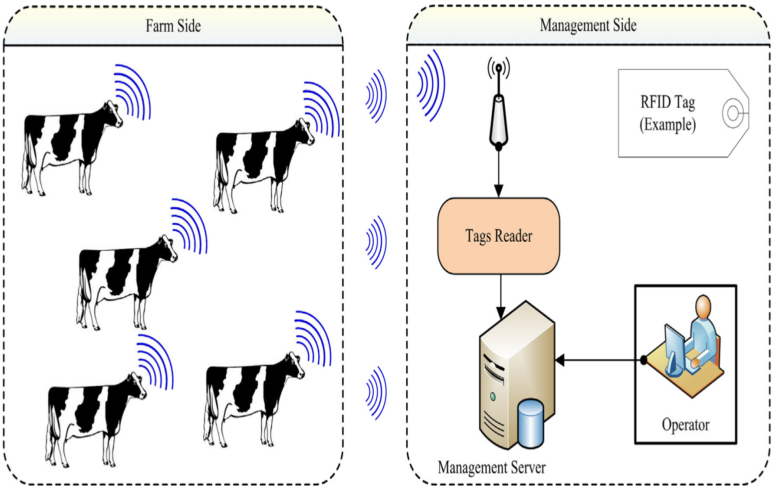

FIGURE 2.5: Illustrates the common architecture of the RFID based identification and tracking system for beef animal. The figure sketches the RFID tags in a farm side, a tag reader, and the location of the management server. The tag reader can be handheld or stationary.

- **RFID-based identification of animals:** RFID technology uses radio waves for identification of human or objects [29] [190]. It is considered as an appropriate technique in a wide range of industries and applications, including agriculture, access control, supply-chain tracking, vehicle parking and tracking, library books tracking, and smart shopping systems [152] [154]. A generic RFID system consists mainly of RFID tags (transponders), an RFID reader, and a management host or server. The generic structure of an RFID system for cattle tracking is shown in FIGURE (2.5).

  RFID tags can be grouped for utilization purposes, operating frequency, and technology. From the utilization standpoint, RFID tags can be grouped into boluses, ear tags, and injectable glass tags [190]. Klindtworth et al. [104] reported that injectable transponders have reached a high level of reliability and security [87]. However, further research is needed regarding transponder recovery from the food supply-chain and sensor integration. Carné et al. [31] argued that electronic ear tags are the most efficient devices because their readability values are greater than those of injectable transponders [4] [63]. A comprehensive review of the readability of 13 different RFID ear tags is presented in Wallace et al. [191].

From the operating-frequency perspective, RFID tags can be grouped into low-frequency (LF) $(125.0\text{–}134.5kHz)$ and high frequency (HF) $(13.56MHz)$ devices. The LF band has been assigned to animal identification [158] [190] .

From the technical viewpoints, RFID tags can be categorized as active tags, which emit radio waves, or passive tags. Active tags operate at high frequencies (455 MHz, 2.45 GHz, or 5.80 GHz) and offer a reading range of 20 – 100 m, whereas passive tags operate at lower frequencies (124 kHz to 960 MHz) and offer a reading range of 0.33–3.30 m [178].

RFID systems have been selected for cattle tracking because they offer non-contact object tracking, can be easily managed remotely, and can be scaled up or down by adding or removing tags with small configuration efforts [87].

In the different countries like USA, Australia, Europe, Canada and Great Britain have applied the radio-frequency based identification (RFID) which is embedded in ear tags for the registration and traceability of animals (cattle) [109] [31].

- **Sketch pattern based animal identification:** The sketching pattern based marking is another visual marking based animal identification method. The animal's furs have also used to recognize the animal based on broken color of different breeds (*e.g.*, Ayrshires, Guernseys and Holstein) [140]. However, sketch patterning based techniques required a skillful drawing ability of individual for coloring and making sketch pattern of cattle's body. The coloring process has always showed the lackness in the demonstration of a standard quality (*e.g.*, high resolution) of sketched pattern; therefore, sketched pattern based recognition technique affects the representation of cattle based on these pattern images [73].

  The temporary animal identification methods cannot be applied for the identification of solid colored based pattern of different cattle breeds (*e.g.*, Redpoll, Milking Shorthorn and Brown Swiss breed). Therefore, classical cattle identification methodology provides security to animals by means of using invasive based techniques such as ear-tagging, freeze-branding or ear-notching or tips [54]. The comparative analysis of classical animal identification methodologies are illustrated in Table 2.1.

TABLE 2.1: Classical animal identification methodology for cattle

Identiifcation approaches attributes	PRM				SRM		TRM	
	ET	MC	ET	FB	IDC	ET	SK	RFID
Reliability	Me	VH	H	VH	L	L	L	VL
Cost	Me	VH	L	Me	L	L	VL	VL
Visibility	VL	NA	Me	H	VH	VH	VH	NA
Longevity	H	VH	VH	H	L	L	VL	L
Risk of harm	L	VL	Me	L	L	VH	VL	VL
Accuracy	H	VH	NA	L	H	L	VL	H
Uniqueness	H	VH	NA	L	H	Me	VL	VH
Data Base Required	H	VH	NA	L	L	Me	NA	VH

Where PIM = Permanent Identification Methodology, SIM = Semi-Permanent Identification Methodology, TIM = Temporary Identification Methodology, ET = Ear-Tattoo, MC = Microchip, FB = Freeze branding, IDC = ID -Collar, SK= Sketching, C = Cost, Me = Medium, VH = Very High, H = High, L = Low, VL = Very Low, NA = Not Available notations are given in Table 2.1.

The discriminatory animal biometrics-based characteristics are unique and immutable biometric identifiers for identification and verification of individual cattle. The detail description of the cattle biometric identifier for recognition of cattle is given in the next subsections.

FIGURE 2.6: Illustrates enrollment of retinal image pattern of cattle.

2.3 Cattle Biometric Identifiers

In this subsection, overview of recognition of cattle based on the primary animal biometric characteristics has been provided in detail. The comparison of different methods for identification of cattle is also illustrated in the next subsection.

2.3.1 Retinal Vascular Patterns

Retinal Vascular Patterns (RVPs) provide considerable cattle identification accuracy; RVPs have features that are similar to human retinal scans. In addition to the high security they provide, RVPs are immutable over time, and the retinal blood-vessel patterns remain fundamentally unchanged in a typically developed animal eye from birth to maturity [5]. Different retinal patterns can also be found in almost all animals, not only beef animals [12] [15]. Therefore, this method can be broadly applied to a wide variety of animals, including goats and sheep. The acquisition of retinal image pattern of cattle using enrollment process is shown in FIGURE (2.6).

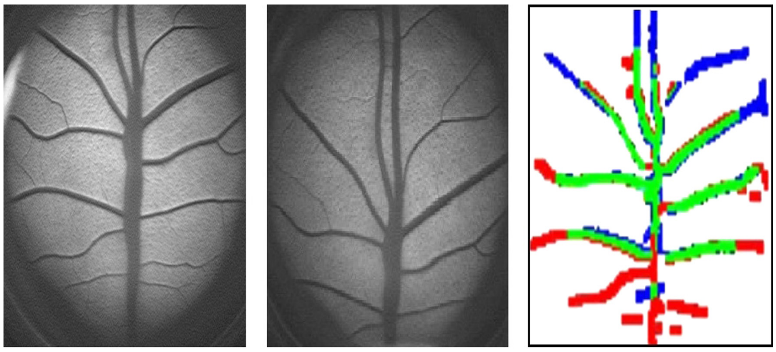

FIGURE 2.7: Illustrates the imahe of retinal vascular patterns of a beef cattle, (a) enrolled retinal image, (b) The same image in (a) collected in a subsequent occasion, (c) extracted and matched retinal vascular patterns from the two images. The reported matching score between the two images is 100%. Images were adopted from Allen et al. [5].

Furthermore, injuries to the eyes cornea do not interfere with the ability to obtain an accurate retinal image [15]. The raw retinal image used for enrollment, and the physiological structure of retinal vascular patterns are shown FIGURE (2.7).

Similar to human retinal patterns, the retinal vascular patterns of individual cattle are confronted with the same challenges of acceptability, collectability, and processing time in recognition of livestock based on their retina pattern [2]. These significant problems that arise in the identification of animal encompass the difficulty for capturing the retinal images of animals due to eye diseases and a failure to control the movement of the animal long enough to capture the retinal images accurately.

Retinal imaging is a primary biometric characteristics for the identification of animals. Based on available literature, retinal images based cattle identification systems has been gaining more advancement for registration of different livestock animals.

In [159], the authors proposed computer vision based approach for identification of $4-H$ beef and sheep. In their study, experimental results are evaluated based on captured retinal image pattern of cattle using retinal imaging technology as a means of permanent identification of $4-H$ beef and sheep. The digital images of 491 beef and 220 sheep were captured using OptiReader Device during $4-H$ enrollment. Based on the performance evaluation, a total of 317 beef and 159 sheep were re-imaged, The verification accuracies were 96.2% and 100% were reported for beef cattle and sheep, respectively. A visual verification exercise showed that individuals could identify a pair of retinal images as a match 98.6 % of the time for beef cattle.

In the similar direction, authors Rojas-Olivares et al. [153] proposed a biometric system for identification of sheep based on their retinal image. The retinal image recognition was applied as an auditing biomarker on 152 lambs of 2 dairy breeds $(Manchega, n = 82; Lacaune, n = 70)$.

The $3-mo$ retinal images were used as reference images and to access operator training and calculate accuracy of the technique. Intra-and inter-age comparisons were made to obtain the matching score (MS) $(0 to 100)$ of pairs of Retinal images from the same eye of different sheep, using Optibrand's software. Operator skill improved with training sessions, however matching score reached a plateau after the sixth session (264 images; matching score = 93.2%).

Regarding lamb traceability, 2.8% temporary ear tags were lost from birth to weaning (traceability, 97.2%), but no official ear tag or mini-bolus losses were reported from weaning to yearling (traceability, 100%).

Inter-age MS comparison, used as the bio-marker for traceability auditing, did not vary by age or breed, on average it being 92.60 %. Using the $3-mo$ RI as reference, all $6-$ and 12-mo RI showed MS>70, which supported 100% lamb traceability. In conclusion, retinal imaging was an accurate technique for auditing the identity of living lambs from weaning to yearling.

Barron et al. [13] reported the retinal recognition as a biometric method for sheep identification. The objective of this study was to assess the accuracy of a commercially available retina biometric based method for sheep identification. They have tested the performance of proposed system on the captured retinal images of sheep in the low light conditions (indoors and outdoors with shade) and different operators exerted any significant effect on the matching score of the built-in pattern matching algorithms. The experimental results are evaluated to determine the recognition performance of the proposed biometric system for enrollment of one retinal image per sheep and two retinal images per sheep (bimodal biometric system). The recognition errors of the one-retina biometric system were estimated to be 0.25% for false matches and 0.82% for false non-matches.

Corkery et al. [41] reported the biometric framework based face recognition for Sheep. They have applied captured face image database of sheep using a holistic analysis by the independent components technique. The experimental results are performed to evaluate the performance of proposed approach independently on several normalized face images from 50 sheep (sets of two, three, and four training images per sheep). The performance of this technique was evaluated on a separate set of images (three normalized face images per sheep) using the cosine distance-based classification method. When 180 to 200 components were extracted, the recognition rate was as high as 95.30% to 96%. As expected, fewer independent components reduced the recognition rate, while a greater number of training images per sheep improved it.

Shanahan et al. [164] proposed biometrics recognition based framework for traceability of beef cattle. The underlying idea is that proposed system has been applied the radio frequency identification (RFID) for the tracking of individual cattle, and the biometric identifier (retinal) for verification of cattle identity. The BioTrack database has been outlined for the storage of retinal images. The advantage of proposed system is (a)-to perform the registration of calf birth and (b)-track movement of cattle using cattle movement monitoring system.

The calf birth registration system has been operational since 1996. From that time on, all calf births have been registered on a central national database. The calf birth registration system is applied to record all the births of cattle and authorize and track the movement of bovines using the CMMS. The combination of these systems gives an accurate picture of the herd characteristics in Ireland.

Recently, Allen et al. [5] proposed a cattle identification framework based on retina image pattern of cattle. For the evaluation of experimental results, 869 bovine animals were used to capture 1738 retinal image modalities (from both eyes), with a maximum achieved identification rate of 98.30%.

2.3.2 Iris Patterns

Iris pattern is a dominant biometric characteristic for identification of the individual animal. The iris pattern of human has many discriminatory features such as furrows, rings, crypts, and a corona. The author Daugman [44] was the first who illustrates an accurate and reliable recognition of individual based on iris patterns using 2D-Gabor filtering [67] based recognition approach to modulate iris phase information and to construct an iris features to code.

The low user acceptability of iris patterns renders iris capturing a difficult task. User misbehavior creates two main problems: blurred images and images occluded by eyelids or eyelashes [39]. These problems become worse when capturing the irises of animals. There is a growing worldwide trend to implement livestock traceability systems. This paper aims to explore how iris analysis and recognition can be utilized on cow identification to enhance cow management in its traceability system.

Lu et al. [122] proposed biometrics-based system for cattle identification based on iris pattern of cattle. The proposed system based on iris analysis includes iris imaging, iris detection, and recognition. In the initial phase, the image quality of the biometric features of captured sequences is first assessed in order to determine the quality of biometric features of iris pattern and a clear iris image is selected for subsequent process.

In second phase, the inner and outer boundaries of iris image pattern of cattle are fitted respectively as two ellipses based on the edge images during image segmentation. After that, segmented iris pattern of cattle is obtained on which normalization of extracted features from the segmented images pattern is performed using geometric method. Finally, 2D-Complex Wavelet Transform (2D-CWT) technique is applied to extract local features and global characteristics of the iris pattern of cattle and the phase of the filtered cow iris is encoded as features. Experimental results indicate the effectiveness of the proposed approach.

The muzzle print images (nose print pattern) is unique and suitable biometric characteristics for identification individual cattle. The complete description of the cattle identification based on muzzle print images is given in the next subsections.

2.4 Cattle Identification Based on Muzzle Print Images

A common problem with conventional cattle identification systems is that they all depend on devices attached to the animal and not on the animal itself. Biometric identifiers, such as muzzle prints and retinal imaging, offer a rapid and secure method for providing a fail safe animal identification system to ensure the traceability of animals back to the farm of origin [25] [126].

On the other hand, animal biometrics faces great challenges with respect to collectability and accuracy, and as such it is considered as a research field still in development.

Human biometric identifiers bear some operational and biometrics characteristics, among them are the uniqueness, universality, and performance. Mapping human biometric traits onto animals is a promising technology for animal identification. It has wide applications that encompass animal classification, animal tracking from birth to the end of the food chain, and understanding animal disease trajectories and analysis of animal population patterns.

The biometric identifier of animal is permanent, time-immutable, and cannot be easily duplicated, forged or altered. Therefore, it is less prone to error and fraud during matching of biometric features. Therefore, based on available literature, animal biometrics appears to answer most of the animal identification requirements [164].

Several biometric traits, or identifiers of animals have been investigated, among them being muzzle print image patterns [15] [17], iris patterns, retinal vascular pattern [12] [13] [14] [16] [153], facial image of cattle [41] [109] [166] and DNA profiles [94]. Each of these can be measured and recorded in the database, providing each animal with a unique identity that remains associated with that animal for life [12] [15].

Moreover, biometrics of animal identification presents an immediate advantage over RFID systems because there is no mass-produced equipment required, and animal biometrics does not require the use of an injected transducer or an affixed ear tag. The following subsections focus on cattle recognition using muzzle point image pattern print images. The comparison of different approaches for identification of cattle are illustrated in the depth level.

2.4.1 Muzzle Print Images

Similar to the recognition of minutiae points in human fingerprint, the captured images of cattle also present different biometrics characteristics, such as grooves, or valleys, ridges and beads structural patterns in the muzzle print images (MPI) of cattle [130] [131]. These uneven muzzle image features, distributed over the dense skin surface of the nose area of the cattle are represented by white skin grooves and by black convex areas girdled by the grooves [131] [166] .

A muzzle print image of the animal can be recognized as an accurate biometric identifier, time-immutable, and proper biometric characteristics, one distinguishing enough to identify an animal with an accuracy comparable to that accomplished by human fingerprints [11]. The muzzle print image of animal have been examined since 1921 [130] [148].

Collecting muzzle print images were achieved by manual data acquisition procedures. The acquisition of muzzle print images of cattle was consisted of several steps. The equipment and materials were used in the data capturing of muzzle print image of cattle are A5-size white papers, stamp black ink, cottons and tissues. The procedures of data capturing are presented as follows:

1. The cattle's head has to be retained still using a rope.
2. Cleaning the nose to reduce snot using tissues.
3. Once the snot is clear, use a thin ink layer using kinds of cotton on the nose and then print on the paper with upward rolling movement. The position of the paper when the printing process and the printing result (*i.e.*, the raw data) are illustrated in FIGURE (2.9). This step is illustrated in FIGURE (2.8).
4. Repeating steps 2 and 3 until the number of data is satisfactory.

The acquisition of the muzzle print image of cattle was captured on $A-5$ paper using blue ink [131] by fixing the head of the beef cattle using a strong rope, head gate or a halter, and spilling, dropping a minimal amount of ink on the dry nose of cattle. The printing of muzzle image pattern (nose pattern) of cattle is shown in FIGURE (2.8).

FIGURE 2.8: Illustrates the printing process of muzzle pattern of cattle on $A-5$ paper [140].

In the manual capturing of muzzle print images of cattle is very hard to get a good data so that not all of the data can be used. The difficulties of the data capturing include the wet condition of the cattle nose and the cattle's nervous feeling. The sweat glands of the cattle are quite big, which may leads to the wetness of the nose. The example of good data is also displayed in FIGURE (2.8)and the examples of bad data are also displayed in FIGURE (2.9).

The muzzle-based animal identification is based on the fact that the muzzle pattern or nose print of different animals of the same species are mostly unique. Therefore, it is concluded that muzzle print image is similar to a human's fingerprint. The muzzle-point based identification approach is a very promising way for cattle identification as it achieves a high accuracy (*e.g.* 90.60% in [140]). Using this approach, there is no need to attach or insert external parts within the animals. Moreover, it complies with most countries legal rules.

Minagawa et al. [130] proposed the first biometric based framework for identification of individual cattle in which the joint pixel intensity feature of the grooves were extracted by

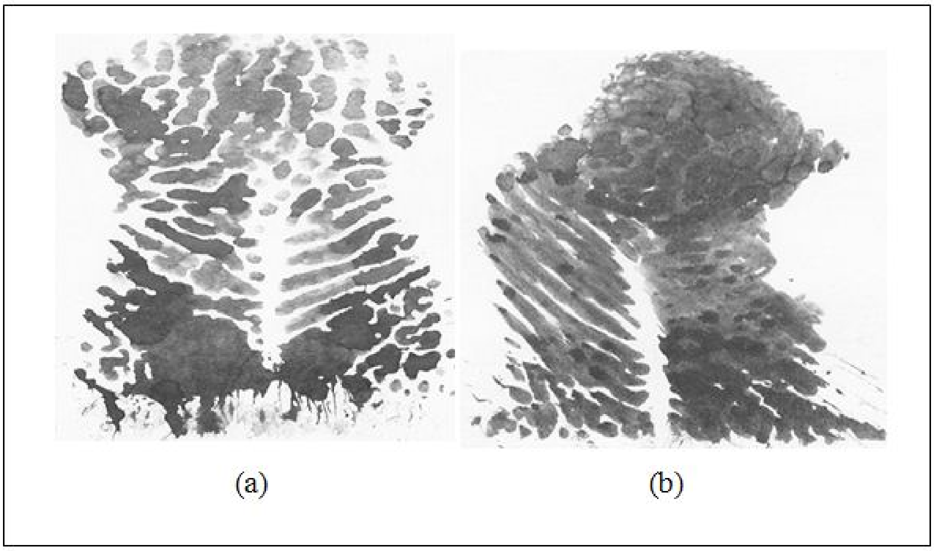

FIGURE 2.9: Illustrates the two example of the bad printing of muzzle pattern lifted on $A-5$ paper, (a) the smeared muzzle print, and (b) the motion blurred muzzle print [140].

applying the image processing techniques, (*e.g.* filtering, binary transformation of captured image, and thinning). The identification was then achieved by matching the joint pixels of a image of cattle with stored image database or to itself. The experiments of their proposed approach were conducted on a prepared database of 43 subjects (cattle) and achieved minimum matching scores at 12% and maximum scores at 60%. The experimental results also illustrated that the identification accuracy was around 30%.

In the similar direction, Speeded Up Robust Features (SURF) and its variant Uniform-SURF (U-SURF) feature extraction based descriptor techniques were used in [140].

Noviyanto et al. [140] performed the experimentation on the 15 muzzle print images of cattle to validate the experimental results for identification of cattle. The authors have applied only 10 images to train the proposed model in the training phase, and 5 images were used in the testing phase. The SURF-based feature extraction based descriptor technique was found superior to U-SURF-based technique one as the former achieved 90% identification accuracy against rotation conditions.

Awad et al. [10] presented a more complete experiment that muzzle print features exhibits unique identification of individual cattle. They applied a Scale Invariant Feature Transformation (SIFT) technique to detect the interesting points of muzzle print images for the purpose of cattle identification. To improve the performance measure of their proposed method, they applied the random sample consensus based classification algorithm to classify the extracted features along with the output of SIFT technique. The method is tested on a population of 15 subjects (cattle), in which 6 muzzle print images for each head of cattle and in total their database includes 90 images ($6 \times 15 = 90$) in the experiment and reported the recognition accuracy of 93.30% at the best accuracy for identification of individual cattle.

In [140] Noviyanto and Arymurthy explored the feasibility of a non-invasive muzzle point based biometric recognition system for identification of individual cattle. In this proposed system, the muzzle print images were captured from 20 cattle using manual procedure as mentioned previously.

On noisy muzzle print images, image processing and enhancement techniques are applied to filter the noises and to improve the quality of captured muzzle print image for identification of beef cattle. After that, the interest points (key points)of muzzle print images were first detected using Scale Invariant Feature Transform (SIFT) key point detection technique , then a local patch around these key points is constructed, and finally invariant features of muzzle images are extracted using SIFT technique. The SIFT features based key point matching is considered one of the most well-known algorithms in the sparse descriptor type applied the SIFT technique to muzzle patterns lifted on paper in order to achieve cattle identification.

To improve the identification performance of proposed system, authors also proposed a new matching refinement technique based on the detected key point of the orientation information. The proposed recognition system is tested and validated on a muzzle point database which is composed of 160 muzzle images left on $A-5$ papers with black ink and taken from 20 cattle breeds. The results shown that the extracted features are independent to different orientation of muzzle point images. They achieved accuracy results using SIFT descriptor techniques only were equal to 0.0167 Equal Error Rate (EER) whereas using SIFT technique along with the proposed matching refinement in SIFT technique minimized the EER to be 0.0028.

In [201] the author proposed a system for identification of cattle using muzzle print images. The identification of cattle is performed using supervised classification techniques on the computed principal component features of muzzle print images. The Support Vector Machine (SVM) [35], Linear Discriminant Analysis (LDA) and Tucker Tensor Decomposition classification techniques [5] are applied to classify the extracted features. The performance of these classifiers are compared on the same dataset of muzzle images with different experiment settings. The experimental results are evaluated by F-score which is equal to 0.750.

El-Bakry et al.[57] presented a method to identify the bovines (cattle races) based muzzle patterns identification. The proposed approach extracts the texture features of muzzle print images using texture feature method. The proposed method has been implemented by using box-counting based fractal dimension based technique. The preprocessing operations such as histogram equalization and morphological filtering (*e.g.*, opening and closing operations) have been used for increasing the contrast and remove noises from the muzzle print images of cattle. After that, fractal dimensions based features are measured as the texture feature for identification of individual cattle. The experimental results illustrated that feature vector for different muzzle print images of cattle are highly symmetry.

In [125], the authors proposed a muzzle-based classification system for cattle using multi class Support Vector Machines (MSVMs) [35]. The box-counting algorithm is applied to compute the feature vectors after detection of key points of muzzle images as feature of cattle. The experiment results reported that advancement of the presented system based on muzzle print features using classification techniques performed the best and achieved the accuracy of 96% classification accuracy in case of increase number of classified group to ten compared to 90% classification accuracy achieved by traditional classification system.

Cai et al. [30] proposed a novel facial representation model of cattle identification using local binary pattern (LBP) texture features of face image of cattle. They have combined normalized gray level feature of cattle face images. Algorithm training was performed independently on 900 face images of cattle (*e.g.*, 30 subjects (cattle) $\times$ 30 face images). Each having a set of 6, 7, 8, and 9 face images of cattle respectively).

To improve the performance, alignment of images is done by applying the sparse and low-rank decomposition technique. These techniques were also applied to align technique for the face images of cattle. The variations in illumination, image misalignment and occlusion provided different representation of features in the feature space during in the testing and matching phase of proposed model. In the matching phase, feature vector of face images of cattle are matched using weighted Chi-square (χ^2) based dissimilarity matching technique to compute the similarity scores. Local Binary Pattern (LBP) based descriptor technique is applied to representation of features and matching scores for recognition of cattle. The reported experimental results shown that the LBP technique achieved 92.50% recognition rate

In [82], Hosseini et al. proposed a recognition system for scanning and identification of cattle based on muzzle pattern of an animal. The proposed system comprising: a scanning segment configured to fit over the muzzle (nose) of the animal and a plurality of scanning cameras attached to the capture the muzzle image pattern of cattle from different angles. The recognition system considerably comprises an image processor for combining and processing scanned muzzle patterns from the plurality of scanning cameras and presenting the processed muzzle pattern on an image viewer. A handle segment has been incorporated a plurality of control buttons and a communication interface for connecting and transferring data to an external device.

Tharwat et al. [177] used the local binary pattern feature extraction and representation technique for identification of cattle. The local binary pattern based feature descriptor technique was done as it extracts robust texture features which are invariant to rotation and occlusion of the muzzle print images. The extracted set of feature of the local binary pattern of muzzle print of cattle has high dimensionality problem, and feature classes of muzzle print images. These problems are solved by applying linear discriminant analysis technique and improved the identification accuracy of proposed recognition system. The Nearest Neighbor, K-Nearest Neighbor (K-NN), Naive Bayes based, and Support Vector Machine (SVM) classification models have been tested to recognize and classify individual cattle based on extracted features. The results showed that their proposed approach achieved 99.50% identification accuracy.

In [2], the authors proposed a framework for identification of cattle breeds. The proposed system presents an invariant biometric-based identification system to identify cattle based on their muzzle print images. The recognition system extracts the muzzle print feature using Speeded Up Robust Feature (SURF) features extraction technique. The extracted features are matched and classified by minimum distance and Support Vector Machine (SVM) classifiers. The proposed approach is tested on a 217 muzzle print images of cattle to evaluate the performance analysis and reported the identification accuracy of 90% at the best as compared with other previous works in the cattle identification.

El-Henawy et al. [58] proposed an artificial neural network (ANNs) based on the identification model of cattle. The proposed model is applied to perform the pre-processing, feature extraction and identification of individual cattle based on extracted features. For feature extraction, box-counting and segmentation-based fractal texture analysis (SFTA) algorithms are utilized. Box-counting algorithm provides a feature vector of 8 features, and SFTA gives 18 features for each cattle image.

For identification of livestock, proposed system compares the similarity between test image of muzzle image feature with stored database. The experimental results reported that SFTA approach had achieved better identification accuracy among all other identification techniques. The proposed approach is superior than previous work. The proposed approach achieved the highest identification precision of 99.97% to recognize cattle.

In [56] Muzzle patterns of cattle, there are uneven features of their skin surface. These muzzle pattern are different from each other similar to fingerprints of the human. The authors proposed fuzzy based cattle identification system for identification of cattle based on muzzle print images using principal component analysis technique.

The proposed system functions by projecting the muzzle features into a feature space that spans the significant variation among non-muzzle pictures. The important features are known as Eigenfaces(principal components) of the set of muzzle images. These principal components are converted to weight vectors and are selected for comparison. Kim et al. [101] proposed a method to recognize the Japanese black cattle based on face image of cattle [101].

2.4.2 Short Review on Identification and Monitoring of Cattle Based on Patents

Willham et al. [195] proposed a system for identification and monitoring of Livestock animals. The proposed framework based system is applied to for store the identification of individual animals. The stored data is estimated on a programmable electronic identification. The data storage module is determined to ensure the identification of the animal.

In this patent, the major limitations are electronic microchips embedded in the body of cattle to get unique encoded identification number to provide identification of the animal. In the preferred invasive and embodiment based programmable electronic identification, the recording and storing information on individual cattle can be lost, and this invention does not provide a low-cost recognition system for getting and maintaining source verification and performance databases. The existing work [195] applied the RFID tags and programmable electronic devices to store the relevant information of animal for monitoring and identification of individual cattle. However, it does not provide the competent level of security to livestock animal.

U.S. patent No. US 8315440 B2, which issued Nov 20, 2012, to James L. and Cambier [33] "System and method for animal identification using iris images" illustrates a system for identification of individual animal based on their iris images.

The identification system includes image capture devices for obtaining an image of an eye of an animal. After that, templates of iris images are generated and stored in the database using generation apparatus. The template generation apparatus extracts a set of pixel data from the captured iris image. The transforming the set of pixel data for the representation of the region of interest (ROI) of the iris region of the eye into templates of the area of interest of the iris region of the eye using the template for use in identifying the animal.

A plurality of comparison templates is obtained by re-sampling the template using a plurality of scale factors. A match score value for each of the plurality of comparison templates is determined by comparing each of the plurality of comparison templates to a previously enrolled template of an eye of a previously identified animal. The system recognizes the animal by determining whether the eye of the animal matches the eye of the previously identified animal by comparing at least one of the match score values to a match threshold value.

U.S. patent No. 4,641,349, "Iris recognition system" [62] discloses the use of the iris images [100] to derive unique biometric identifiers for identification of humans and animals. However, this invention does not illustrate specific techniques for extraction of features from iris of animal irises.

In the Similar direction, U.S. patent No.6,424,727 "System and method of animal identification and animal transaction authorization using iris patterns" [134] demonstrates an identification system for animal identification based on circular iris features. However, it does not present a method of iris recognition which is more suitable for animals having non-circular iris features.

U.S. patent No. 6,229,905 "Animal identification based on irial granule analysis" [175] describes an animal identification method based on the shape of iridial granules. The identification system recognizes the horse and cattle based on the eyes of most at least 2 years old. But proposed identification system does not perform accurate matching of irial granule features with stored database due to unable to determine gray level differences between pixels in an input image and reference image of cattle.

U.S. patent No. 6,614,919 "Method of extracting iris region and individual identification device" [176] depicts the proposed recognition system based on iris code for horse eyes. The recognition system uses a precise pupil outline of horse eyes and finds the region of interest based on approximation of the outer iris boundary. The recognition system performs feature extraction from iris area below the pupil of horse. The encoding mechanism is applied to encode the iris texture features into suitable iris code.

The iris code is generated by using Gabor wavelet transformation technique. The Gabor wavelet technique produces a digital iris code using phase changes in the output of the wavelet encoding process. After that, the iris based recognition system performed the similarity matching of input query iris template code and reference iris template codes using distance metric techniques. However, this invention does not illustrate any technique to eliminate irrelevant regions of the iris or pupil of horse which are obscured by eyelids or using a scale matching based technique to mitigate the effects of various changes in pupil size.

Recently, U.S. Patent 8,261,694, "Cattle management method and system" [149] proposed a system and method of cattle management in a feedlot. The proposed system provides better management of cattle for health monitoring in the livestock framework. The system produces high economic return to the feedlot and provides high profit to producers for each animal in the feedlot. The proposed system is efficient and accurate for measurement, and movement of individual cattle based on recorded data [80]. But the proposed system does not operate in real-time scenario online verification of cattle based on recording and correlation of historical data.

After the literature review, following research gaps are identified for identification and monitoring of cattle:

- No research works have been done for recognition of cattle based on muzzle point image pattern which is captured by smart devices (*e.g.*, smartphone, digital camera, and smart watch) for recognition of cattle.
- In the available literature, few research works have been done in the field of recognition of cattle based on face images of cattle using computer vision based approaches and pattern recognition approaches, deep learning based recognition and representation methods.
- No research works have been done for recognition monitoring of livestock animals (cattle) using smart devices in the real-time scenario for online verification of false insurance claims of cattle or other animals.

- Real-time implementation of cattle recognition systems are not found in the public domain or available based on their primary biometric characteristics such as face and muzzle point images for the identification, registration, traceability and monitoring of health of cattle or livestock throughout world.
- No research works have been done to solve the major challenging problems of verification of false insurance claims, identification of missed animals or swapped animals, reallocation of the animal at slaughterhouses throughout the world using animal biometrics-based recognition and verification systems.
- In the public domain, there is no such muzzle point image pattern and face image database available to perform the better research and analysis for recognition of individual cattle or species.

2.5 Research objectives

The recognition of animals is an emerging research in the animal biometrics. It provide the opportunity for the realization of several useful applications, such as registration of animals, improved security against swapping of animals, accurate population of species, tracking, recognition and verification of animals. There are following objectives of this research:

1. The objective of my research is to design and development of an automatic system for recognition and verification of cattle based on their animal biometric characteristics such as face image and muzzle point image pattern (nose pattern).
2. To explore the possibility of cattle recognition using computer vision, image processing and animal biometrics approaches..

3. To validate the prepared face image database of cattle by applying the existing hand-crafted texture feature-based descriptor techniques and appearance based feature extraction and representation techniques for recognition of individual cattle.

4. To validate the prepared database of cattle for the recognition and verification of cattle based on multimodal biometric characteristics using fusion based recognition approaches, computer vision and pattern recognition approaches.

5. To solve the cattle recognition problem using muzzle point images, we have applied the low-cost devices to capture the muzzle point image pattern and the face image of cattle for the preparation of database in the acquisition phase. The cattle recognition system is cost-effective because the low-cost acquisition devices (*e.g.*, smartphone, smartwatch, smart Tablet, or digital camera) are deployed for identification and verification of cattle based on their biometric features.

6. Investigate the feasibility of livestock (cattle) recognition system using texture based fusion methods, hybrid texture feature extraction, and representation approach, deep learning based cattle recognition approaches.

7. Finally, an attempt has been made to fill the research gap after completion of the comprehensive review in the field of animal biometrics.

8. For doing research, we have prepared the database of muzzle point image pattern and face image database of cattle in the public domain for the research purpose. The detailed experimental design and, protocols along with train-test database splits are shared to encourage other multidisciplinary researchers, scientists, biologists, and veterinary professionals to report comparative results and depth analysis.