Animal identification: from traditional methods to Biometric approaches

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Abstract

Individual animal identification helps with effective management, health monitoring, and legal compliance across various domains, including livestock management, wildlife conservation, pet identification, and scientific research. Despite the importance of reliable identification systems, there remains a lack of a unique, tamper-proof, and dependable method. This paper explores the evolution of animal identification techniques, from traditional methods such as branding and tagging to contemporary biometric approaches, which aim to enhance the precision and reliability of animal identification. Since animals are unable to communicate verbally and they often resist human interaction, capturing biometrics presents unique challenges. By examining the advantages and limitations of different identification methods, the study emphasizes the growing importance of biometric technologies that leverage unique biological characteristics, such as DNA, retina scans, and fingerprint patterns. While biometric identification systems offer notable benefits in terms of reliability, accuracy, and animal welfare, they also face challenges related to specialize equipment's developed for animal trait(s) acquisition for finding the unique features may be used for their identification, cost barriers, and issues surrounding standardization. The paper concludes that while biometric identification holds potential, the most effective solutions may involve the integrating both traditional and modern methods to overcome the practical challenges associated with them.

Keywords: Animal biometry; Animal Identification; Biometrics Identifications; UAI (Unique animal identifier)

Introduction

Animal identification has been practiced for a long time; it has evolved from simple ownership marking to sophisticated modern systems serving multiple purposes. The ability to reliably identify individual animals constitutes a foundational element of modern animal management, whether in agricultural, conservation, or companion animal contexts, particularly in breeding and performance evaluation programs where accurate recording of individual animals is essential (Govindasamy et al., 2023). The importance of animal identification is very significant as it concerns animal welfare, emphasis on food safety and technological advancements. Recent developments in precision livestock farming have enabled the use of automated identification, sensor-based monitoring, and real-time data collection in livestock production systems (Berckmans, 2017). It has grown significantly in recent decades due to globalization.

Tracing animals throughout their lifecycle from a public health perspective has become essential for ensuring food safety and managing disease outbreaks. Increasing efforts on accurate identification of individual animals to take protective measures towards the endangered animal species to safeguard them are of significant importance. This paper documented and examined the animal identification methods from traditional approaches to the rapidly evolving field of biometric identification.

Traditional identification methods

The traditional systems used for individual animal identification has evolved over time is given in Fig 1. Some of them are attached with body and some of them rely on visual marks on animal body.

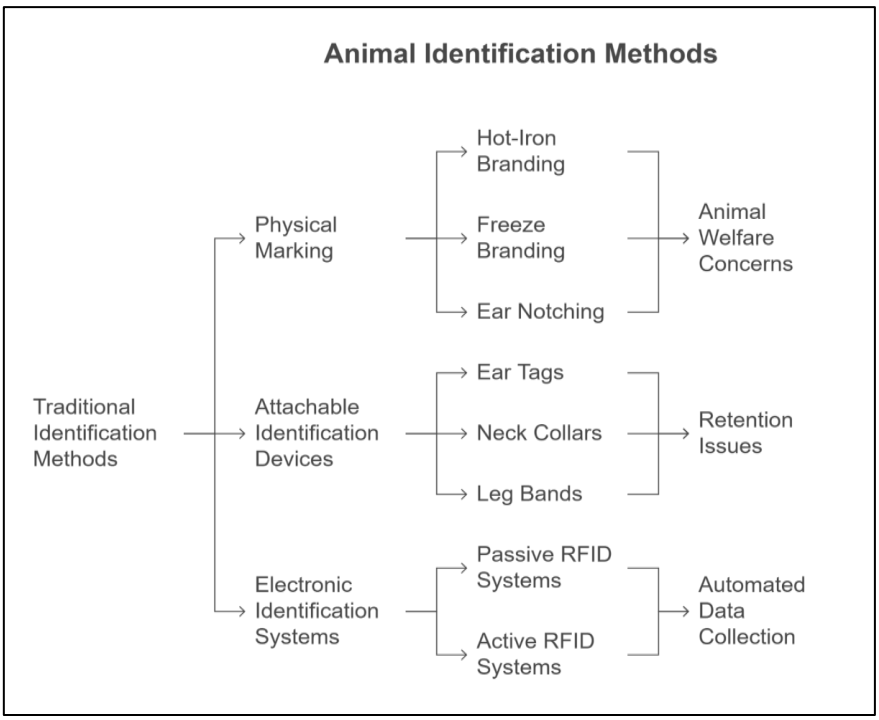

Fig.1. Animal Identification method

Physical Marking

Physical marking methods represent some of the earliest approaches to animal identification, livestock branding dating back to approximately 2700 BCE in Egypt. These techniques include hot-iron branding, freeze branding, and ear notching (Fig 2), all of which create permanent, visible marks on the animal's body to establish identity and ownership. These methods have historically been the foundation of livestock management systems worldwide for a very long time.

Each method's implementation of physical marking varies, hot-iron branding applies a heated metal symbol to the animal's skin, creating permanent scar, while freeze branding uses extreme cold to destroy pigment-producing cells, resulting in white hair growth. Ear notching involves making precise, standardized cuts in the ear's margin, particularly common in swine production, creating a pattern that can be used to identify individual animals or their origins.

Despite their historical significance, physical marking methods face increasing scrutiny due to animal welfare concerns. These methods cause varying degrees of pain and stress to animals. Additionally, these systems provide limited individual identification capacity, with ear notching systems particularly constrained in the

number of unique identifiers they can generate. The permanence of these marks, once considered an advantage, may now be viewed as a limitation in dynamic management systems requiring data flexibility.

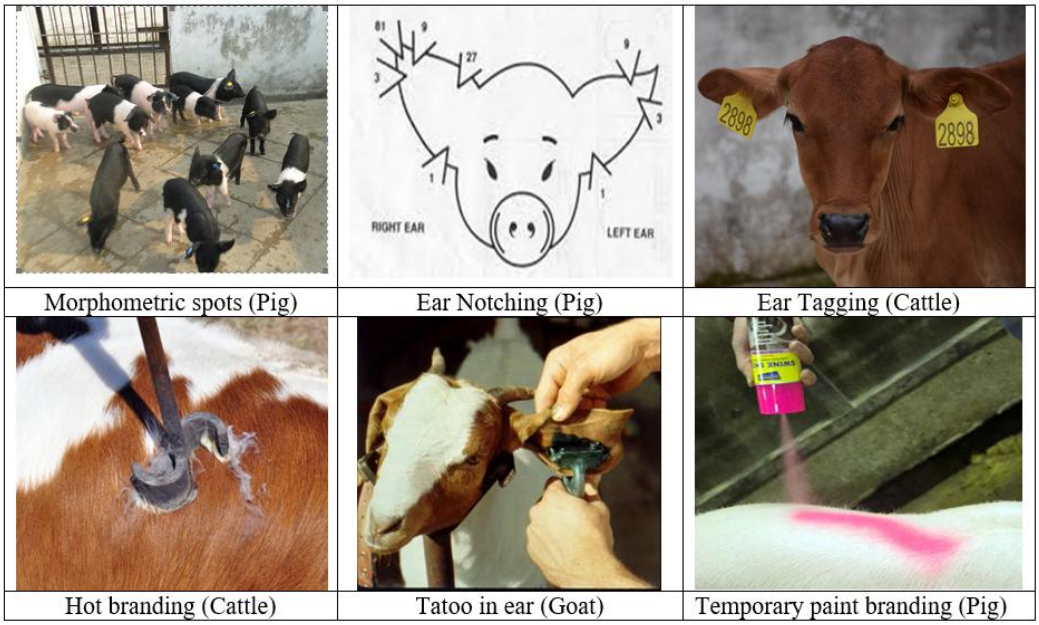

Fig 2. Traditional Animal Identification Method

Attachable Identification Devices

Attachable identification devices are the most widely implemented animal identification. These devices, primarily consisting of ear tags, neck collars, and leg bands, provide visible identification that can be customized with barcode, numbers or color-coding systems to identify individual animals or groups. Their non-intrusive nature and adaptability have made them a good choice across numerous production environments worldwide.

The relative simplicity, affordability and adaptability of ear tagging systems have made them the default choice for livestock management, despite significant limitations in retention rates. Ear tags function by attaching themselves to the animal's ear using specialized applicators, while neck collars go around the neck region and leg bands are attached to limbs. These systems can be equipped with various technologies, including visual identification elements, electronic components and GPS tracking capabilities for location tracking.

The primary advantages of these devices include their ease of application, relatively low cost and high visibility for quick identification. There are significant limitations, especially regarding retention rates, with research indicating tags are lost at 5-20% each year depending on environmental factors and tag design. Other drawbacks include the risk of infection at attachment sites, challenges in reading tags from a distance, and vulnerability to deliberate tampering or removal. Despite these limitations, the practical benefits of attachable identification devices guarantee their importance in animal identification systems.

Electronic Identification Systems

Traditional visual identification methods have many drawbacks; therefore, electronic identification systems are incorporated for reliability and enhance functionality. These systems utilize Radio-Frequency Identification (RFID) technology, consisting of microchips encased in injectable transponders, ear tags, boluses or other carriers that store unique identification codes electronically. RFID tags transmit animal identification information using radio waves (Bodkhe et al., 2018).

Electronic Identification system's operational mechanisms are based on system types. These systems are mainly categorized as Passive RFID systems, activated when they come into proximity of compatible readers. They lack internal power sources and rely on electromagnetic fields emitted by the reader to power the transponder, enabling it to transmit stored data. Advanced active transponders are usually battery power enabling the reader to read them from a long distance. In addition, they can be used to track animals body temperature or for actively monitoring them. When RFIDs are scanned, they transmit unique identifiers to the database for storage and future retrieval for future identification or medical history.

Electronic identification systems offer many advantages, including automated data collection, reduced human error, and improved traceability throughout production and distribution chains, although their adoption depends on cost, infrastructure, and user acceptance in practical livestock operations (Bolte, 2007). The data collected from these systems have become standard in many regulatory environments due to their reliability and data integration capabilities. However, many challenges persist, including its cost of implementation compared to

traditional methods, occasional failures occur due to electromagnetic interference, and batteries are a big limitation for active systems, as they affect longevity. Despite these challenges, electronic identification evolved significantly, with ongoing improvements in reliability, functionality and cost-effectiveness.

Chip-based modern devices available in India:

In India, several modern electronic identification devices are available for livestock management and traceability. These devices help in maintaining proper records of animals, improving disease monitoring, and supporting efficient farm management. Among the available systems, RFID-based ear tags are the most widely used because they are affordable, easy to apply, and supported by several government livestock identification programs. Other devices such as injectable RFID microchips and rumen bolus devices are also used for permanent identification, although their use is still limited due to higher cost and the requirement of specialized readers. In recent years, advanced monitoring technologies such as GPS tracking collars and smart ear tags with sensors have also started appearing in the Indian livestock sector, especially in organized dairy farms and research projects. However, the large-scale adoption of these modern technologies is still developing, mainly due to the initial investment cost and the need for technical infrastructure. The availability and approximate cost of some commonly used modern identification technologies in India are presented in Table 1.

Table 1. Availability of Modern Animal Identification Technologies in India

Identification Method	Availability in India	Approximate Cost per Animal (INR)	Source
RFID Ear Tag	Widely used in livestock identification programs and easily available in the market	₹50 – ₹200	Invest India (2021)
RFID Ear Tag (Commercial Supply)	Available through livestock technology suppliers and veterinary equipment providers	₹100 – ₹500	ID Solutions India (2023)
QR / RFID Livestock Tag	Available through agricultural equipment suppliers and exporters	₹20 – ₹100 per tag	Exporters India (2023)
Injectable RFID Microchip	Available through veterinary suppliers but less commonly used	₹250 – ₹600	Furora Pet (2026)
GPS Tracking Collar	Available through specialized livestock monitoring technology companies	₹3,000 – ₹10,000+	Invest India (2021)

Potential benefit of chip-based system

Chip-based animal identification systems offer several important advantages over traditional identification methods such as branding, ear notching, or simple visual ear tags. In traditional systems, identification marks can fade over time, become difficult to read, or may even be intentionally removed or replaced, which can lead to errors in identifying animals. In contrast, chip-based systems such as RFID tags or microchips store a unique digital identification number that can be quickly read using an electronic scanner. This makes the identification process faster, more accurate, and less dependent on human observation. Another important benefit is that electronic chips can be connected to digital databases where detailed information about each animal, including health records, vaccination history, breeding data, and ownership details, can be stored and easily accessed. This improves farm management and helps authorities trace animals during disease outbreaks or food safety investigations. Chip-based systems also reduce the chances of fraud or misidentification because the electronic code is unique and difficult to duplicate. In addition, these systems support automation in modern livestock farming, allowing farmers to monitor animal movement, feeding behavior, and productivity more efficiently. Although the initial cost of chip-based identification may be higher than traditional methods, the long-term benefits such as better record keeping, improved traceability, and enhanced management make it a valuable and reliable solution for modern livestock management.

DNA profiling

DNA profiling is the most definitive form of biological identification; it utilizes the genetic uniqueness of identifying animals which make it nearly perfect and highly accurate. This molecular method analyzes distinct genetic markers, including single nucleotide polymorphisms (SNPs) and short tandem repeats (STRs), which are widely used in modern molecular and genomic studies in livestock populations to generate unique genetic profiles with extremely high accuracy.

DNA profiling is time-consuming and is costly in comparison to other identification methods used in the animal industries, it requires collection of samples from animals then processing it in the laboratory and then analysis of the DNA for its profiling. The sampling process begins by collecting the samples such as blood, hair follicles, tissues or other cellular materials. Following DNA collection, DNA extraction takes place in which DNA gets amplified through polymerase chain reaction (PCR) and analysis of specific genetic markers. Recent advances in genome sequencing and mitochondrial DNA analysis have enhanced the precision of molecular

identification and diversity studies in animal populations (Das et al., 2024). Modern techniques have streamlined the process of DNA profiling, with automated systems capable of processing large sample volumes and complex software interpreting genetic profiles through mathematical analysis.

DNA profiling has many advantages like permanence of gene in an animal for lifetime, it is definitive in nature and impossible to transfer or falsify. The cost of DNA profiling for animal identification has decreased significantly over the past decade, while processing time has reduced from weeks to days, making it more viable. Despite its advantages, DNA profiling has many challenges like its relatively high cost compared to most alternative identification methods and the time taken by labs to process may also vary from hours to days depending upon the technology and infrastructure.

Biometric methods for animal identification

Animal identification using biometric identification methods identifies unique biological traits to accurately and reliably identify animals (Fig 3). Recent studies have shown rapid development of computer-vision and deep learning an artificial intelligence-based biometric identification systems in livestock (Luthra et al., 2024, Meng et al., 2025). These identification techniques are increasingly used for livestock management and research due to their precision. Modern biometric and sensing technologies are often combined with wearable sensor systems to enable automated monitoring and intelligent livestock management (Ding et al., 2025). Unlike traditional methods, biometric identification eliminates the risk of tampering, enhancing security and efficiently identifying animals.

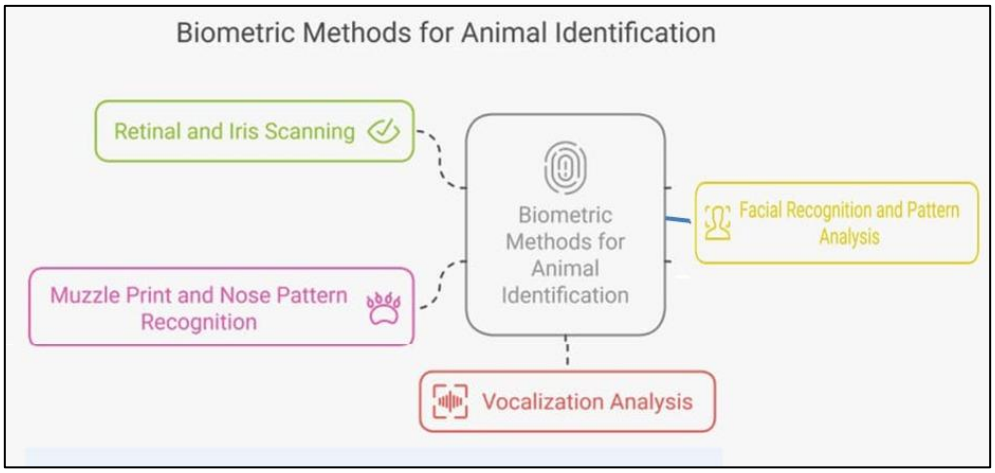

Fig. 3. Biometric methods for animal identification

Retinal and Iris Scanning

Sophisticated biometric approaches to animal identification like retinal and iris scanning technologies, utilizing the unique vascular patterns of the retina and structural characteristics of the iris that remain stable throughout an animal's lifetime (Fig 4.a and Fig 4.d). These physiological features offer highly individualized biological markers that cannot be transferred, duplicated, or easily altered providing a level of identification security unmatched by traditional methods. The technology has proven especially valuable in high-value livestock operations and regulatory compliance.

The retinal scanning process needs specialized cameras to capture images of the eye's posterior region, focusing on the distinctive pattern of blood vessels radiating from the optic disk, and retinal image–based identification systems have been successfully developed for individual recognition in livestock species (Mustafi et al., 2021, Roy et al., 2020). These images undergo digital processing to identify bifurcation points, branch numbers, and inter-bifurcation distances, creating a unique vascular "fingerprint" for each animal. Similarly, iris recognition technology analyzes the trabecular meshwork patterns of the iris, though implementation challenges include the lack of specialized cameras designed specifically for animal subjects and the difficulty of proper image capture in non-communicative livestock.

Retinal and iris scanning provide exceptional identification accuracy, with bovine retinal vascular patterns providing approximately 250 unique characteristics per eye and achieving an identification accuracy exceeding 99.5% in controlled environments (Mandal et al., 2023). The key advantages include uniqueness, permanence and the impossibility of transfer between animals. However, during practical implementation significant challenges exist, like the need for specialized equipment, the necessity of restraining animals during scanning, variations in image quality depending on environmental conditions, and species-specific anatomical variations that necessitates customized approaches.

Auricular venation pattern is also used for individual identification. This procedure requires to create an artificial environment to eliminate external noise and light while capturing the auricular venation pattern (Dan et al., 2021, 2023).

Facial Recognition and Pattern Analysis

Facial recognition and pattern analysis uses computer vision technologies to identify animals through their distinctive visible characteristics such as facial structure, skeletal structures and natural markings. Facial recognition and pattern analysis systems capture high-quality digital images and use sophisticated algorithms to identify structures, proportions, and distinguishing features, creating mathematical algorithmic functions as biological which could be used as barcodes for that animal. Wildbook is an automated image-based wildlife identification and data management system that uses crowdsourced photographs to track individual animals, generate high-resolution population databases, and support conservation research and species census for identification of wild animals (Berger-Wolf et al., 2017).

Facial recognition and pattern analysis approaches offer several advantages over others as they are non-invasive and they cannot be lost or transferred. Facial recognition systems also cost less than its counterpart and allow for remote identification without physical restraint. They can integrate with existing camera infrastructure and enable automated monitoring. However, there are challenges that remain, including the need for high-quality images under proper lighting conditions which may also require restraining the animal for proper photographs, substantial computational resources and its performance vary across different environments. The systems for facial recognition require initial database creation and may struggle with juvenile animals whose features are in the developing phase. Despite this, advances in artificial intelligence have improved the accuracy and practicality of these technologies for field applications across various species including cattle, endangered wildlife and even marine mammals.

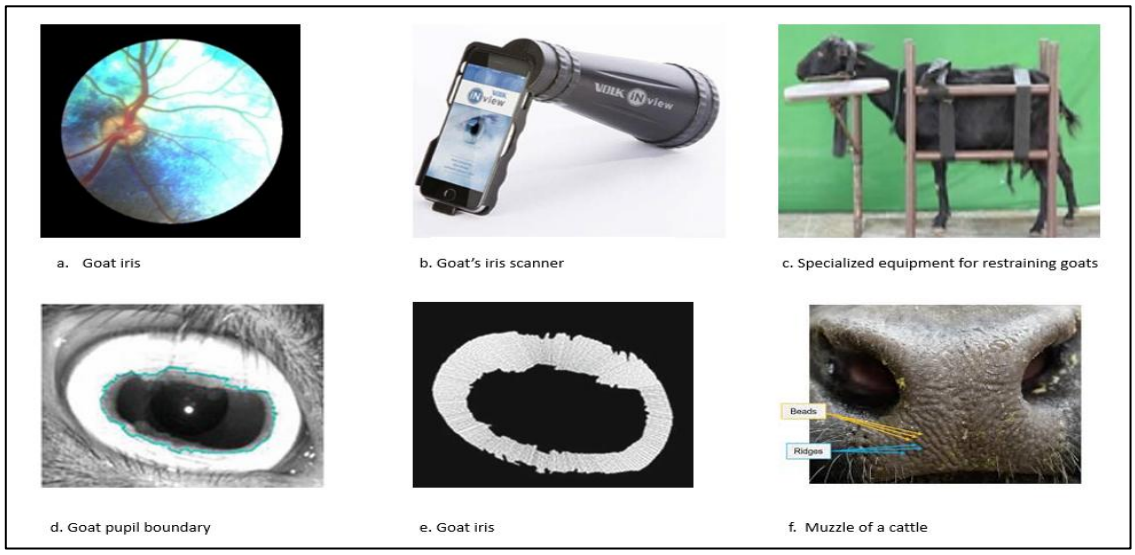

Fig. 4. Different biometric traits for identification of animal

Muzzle Print and Nose Pattern Recognition

Muzzle print and nose pattern recognition systems utilize the unique patterns present on the skin surfaces of certain animal species as biological identifiers, and recent studies using image processing and deep learning techniques have demonstrated high accuracy in identifying individual cattle from muzzle images (Li et al., 2022). Similar to human fingerprinting, muzzle patterns are captured either by using a digital camera or by pressing the animal's muzzle onto a paper surface after applying ink. Bovine muzzle prints—the patterns on cattle noses—have been documented as unique identifiers since the 1920s, while similar approaches have been developed for canine nose patterns and other species with distinctive dermatoglyphics features. In the first method, when capturing muzzle images (Fig 4.f), factors such as the angle between the head and the camera and ambient lighting must remain consistent during both registration and verification for accurate identification which is quite challenging. The focal length of the camera and the distance between the muzzle and the camera position must also remain the same during both registration and verification to ensure better accuracy

Applying ink to the muzzle and obtaining a print on paper is a tedious process, as the pattern depends on the position of the muzzle. This method has been used for identifying Murrah buffaloes. Some animals contain unique muzzle patterns; the analysis of these patterns can be used for identification of these animals. Muzzle patterns are captured either by physically pressing the animal's muzzle against paper after applying ink or by

digital photography under controlled conditions. The digital approach requires consistent lighting, standardized positioning and precise camera settings to maintain comparable images between registration and verification. After capturing these images undergo digital processing to extract pattern features, including ridge bifurcations and the relative distances between ridges. These features are then converted to mathematical models that can be stored in databases and can help with future comparisons for identification purposes.

Nose pattern recognition and muzzle prints offer several advantages which includes the uniqueness, permanence of the patterns and its relative non-invasiveness nature compared to some alternative methods, and the potential for integration with digital systems. Pig muzzle images can serve as a reliable biometric identifier, as stable features such as contour shape, pore locations, and hair density can be extracted using image processing techniques and used for accurate individual discrimination (Karthik et al., 2017). However, several practical challenges are present which are impeding its widespread implementation. These include the difficulty of obtaining good quality images from non-cooperative animals, the requirement for standardized image capture conditions and the requirement for specialized equipment, such as barricades or stands along specialized software needed for analysis. Physical muzzle printing methods, while effective, prove several particularly challenging in field conditions and often require animal restraint. As a result, their adoption has been limited, primarily used for research applications and specialized high-value operations.

Vocalization Analysis

Vocal analysis is a good biometric way of identifying animals through their unique vocal signature. The procedure records animal sounds via acoustic sensors, then processes them digitally and analyzes parameters like frequency distribution and temporal patterns using machine learning algorithms, and recent studies have shown that machine-learning-based vocal analysis can be used to detect behavioural and emotional states in cattle (Gavojdian et al., 2024). Main advantages include remote monitoring capability, complete non-invasiveness and the ability to simultaneously assess welfare indicators through vocal biomarkers.

Vocal analysis faces several limitations like the technology is vulnerable to environmental noise interference and vocalization variability based on physiological state and context. It also requires specialized equipment for recording sound, significant resources for computation and species-specific algorithm development. Due to these challenges vocalization analysis is a valuable complementary animal identification approach rather than a standalone identification system for most animal management applications, though continuing technological advancements may enhance its feasibility in the future.

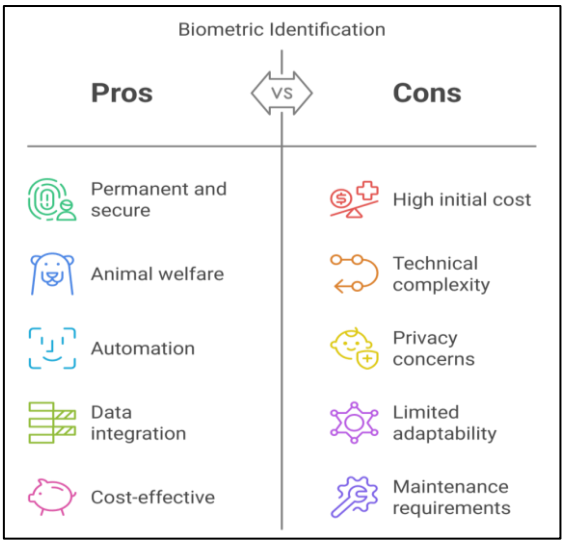

Fig. 5. Pros and cons of Biometric Identification

Pros and cons of Biometric Identification

Biometric identification like nose printing, iris scanning and DNA profiling has many pros such as biometric animal identification is permanent, secure and cost effective in long term purpose. But it comes with some challenges like it raises privacy concerns and can be expensive to implement initially (Fig 5).

Pros of Biometric Identification

Permanence and Security

Biometric identification is more reliable as biological characteristics cannot be lost, removed, or traded between animals. Unlike physical identifiers that can be lost or removed from the animal, biometric markers are

intrinsically linked to the individual and are permanent, providing a level of security that conventional methods cannot achieve. Biometric identifiers are non-transferable which significantly reduces fraud opportunities, as traditional identifiers like ear tags or neckbands can be intentionally removed or swapped.

Animal Welfare Considerations

Many biometric identification methods are non-invasive or minimally invasive making them gentle towards animals and causing little to no harm, this represents a significant welfare improvement over traditional method. Techniques like facial recognition, pattern analysis and vocalization assessment require minimal physical interaction with the animal. Even methods such as retinal scanning are far less stressful compared to restraint-intensive procedures like tagging or branding which cause distress. These methods align with evolving regulatory rules that prioritize animal welfare and overall well-being.

Automation and Data Integration

Biometric systems have exceptional potential for automation and improving data accuracy. Advanced systems can capture and record biometric data during everyday activities without the need for dedicated handling sessions, which is a key feature of precision livestock farming systems that integrate sensors, identification technologies, and real-time monitoring of animals (Bernabucci et al., 2025). Since biometric analysis is digital in nature it enables seamless integration with databases and management software, helping farmers to track and manage approaches that link individual identification with real-time health data, behavioral observations and environmental conditions.

Cost-Effectiveness Over Time

Although higher initial implementation costs of biometric systems they often demonstrate economic advantages over a period of time (Fig 6). Traditional methods require ongoing costs through replacement of lost tags, neck bands, labor for reapplication and errors from misidentification. A positive return on investment for facial recognition systems in dairy farms can be achieved in a large farm exceeding 500 animals over a substantially long tenure of more than 3 years, primarily through saving labour cost, improved management and lower identifier replacement costs.

Cons of Biometric Identification

Technological Limitations

Current technologies implementing biometric systems face reliability challenges in real-world scenarios. Environmental factors like lighting variations, moisture, dirt and movement can significantly impact data capture for visual biometric methods. The controlled conditions of laboratory testing many a times don't reflect the challenging environments of typical livestock operations or wildlife monitoring settings, resulting in degradation in performance during practical implementation. Many biometric methods also require significant computing resources, which can be challenging in remote agricultural or conservation areas with limited connectivity.

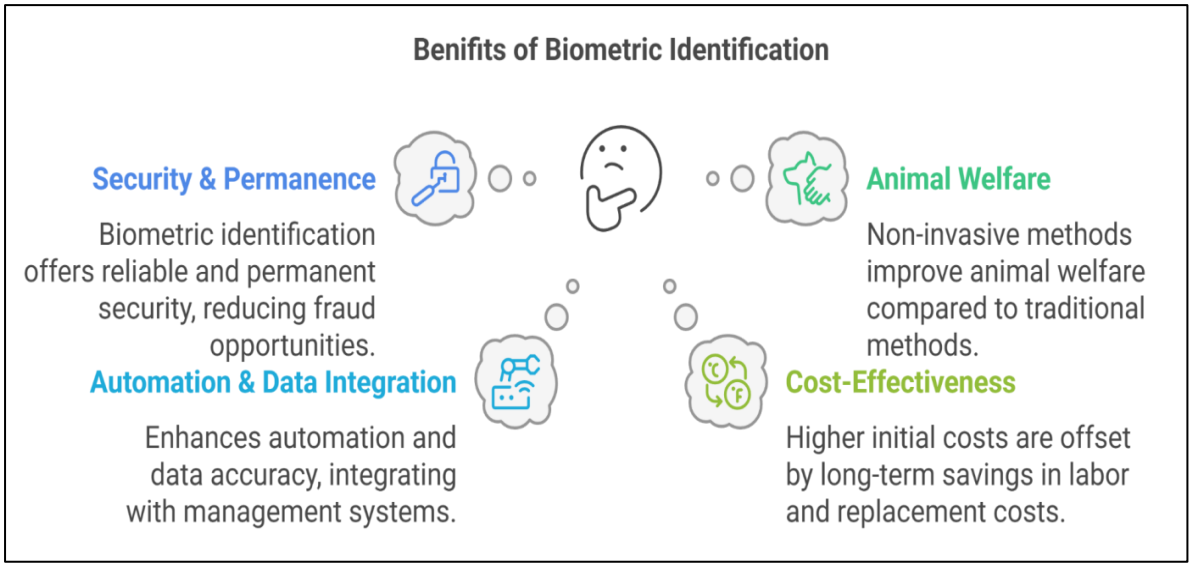

Fig. 6. Benefit of biometric identification

Implementation Costs

The high cost of implementing a biometric system remains a major challenge, particularly for smaller farm operations. Similar concerns regarding cost, infrastructure, and user acceptance have also been reported for electronic animal identification systems in livestock markets (Bolte, 2007). Biometric systems typically require specialized equipment like camera, sensors, software licenses, training and infrastructural upgrade. Initial development of facial recognition system requires substantial investment compared to traditional identification methods. Additional ongoing expenses for system maintenance, updates and technical support further increase financial burden.

User Acceptance and Training

The successful implementation of biometric systems requires major changes to existing practices, often encountering resistance from users who are accustomed to using traditional methods. The complexity of the technology can overwhelm users without strong technical backgrounds.

Standardization, Regulatory, and Ethical Challenges

The rapidly evolving biometric identification technologies have outpaced regulatory rules and industry standards. Unlike traditional identification methods which follow standard guidelines, biometric approaches don't have consistent protocols for data collection, analysis and storage. The challenges make it difficult for systems to work together and exchange data between different platforms or organizations (Fig 7). These technologies raise ethical and welfare concerns regarding animal handling, data use, and regulatory compliance, which are increasingly discussed in animal welfare and ethics literature (Mota-Rojas et al., 2023).

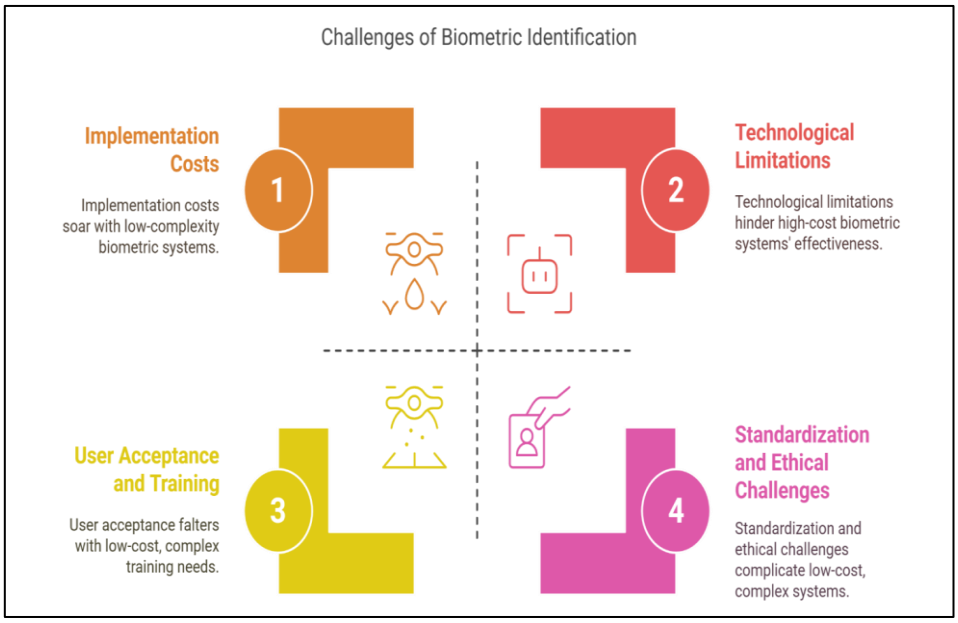

Fig. 7. Different Challenges of Biometric identification

Conclusion

In this paper, the evolution of animal identification systems from ancient physical marking techniques to advanced biometric systems is highlighted despite not being fully tamper-proof. This review has examined the transition from traditional methods to electronic identification and emerging biometric approaches that utilize animals' inherent biological traits for their identification. Research indicates that biometric identification methods offer notable advantages in permanence, animal welfare and automation. Their non-invasive nature aligns with evolving welfare standards and regulatory rules, while these systems enhance security against tampering or transfer while enabling seamless integration with digital management systems for comprehensive monitoring beyond identification.

The paper also described the challenges and obstacles in implementing biometric identification systems which hinder their widespread adoption. Technical limitations affect its reliability under field conditions, where issues such as the need for animal restraint and animals being non-communicative in nature pose a significant problem. High initial costs restrict accessibility for smaller farm operations and lack of standardization further complicates integration across systems. Furthermore, specialized equipment for restraining needed for many biometric approaches making deployment difficult in resource-constrained environments.

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