Available online at www.worldnewsnaturalsciences.com

World News of Natural Sciences

An International Scientific Journal

WNOFNS 54 (2024) 26-37 EISSN 2543-5426

Computer vision-based precision livestock farming: An overview of the challenges and opportunities

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ABSTRACT

Different measures have been employed by livestock caretakers for the detection and monitoring of health and welfare status of their livestock. However, being performed manually has made the task a labor intensive, costly and time-consuming exercise. Various modern technologies have been explored by many studies to improve the livestock production, from among which computer vision has proven to be highly effective and efficient; nevertheless, a thorough investigation into the application of computer vision reveals noteworthy obstacles to embracing and implementing it in precision livestock farming such as cattle farming. Among the obstacles are 1) unavailability of reliable public cattle datasets and 2) lack of tested and trusted generalized methods/models employ in conducting research and experiment on new datasets. This paper presents an overview of the challenges and possible directions and future research opportunities of computer vision-based precision livestock farming.

***Keywords*:** Cattle, Challenges, Computer vision, Opportunities, Precision livestock farming

1. INTRODUCTION

Recently, there is an exponential growth in the production of cattle across the world majorly for their use and profit (De Vries and Marcondes, 2020). While this growth has significantly increased economic value, the method of producing the livestock, though advances

(Received 26 February 2024; Accepted 23 March 2024; Date of Publication 25 March 2024)

efficiency and reduces cost of production, it has also brought in new challenges regarding the health and welfare maintenance of the animal (De Vries and Marcondes, 2020). From one point of view, cattle being among the livestock that have high economic value need reliable production systems such as ranch.

A ranch is a farm consisting of a large tract of land along with facilities needed to raise livestock (especially cattle), however, these production systems are not only unreliable due to the machinery and technology put in place but are mishandled by unskilled workers. From the other point of view, dairy products consumers have showed keen interest in the conditions and environment under which the dairy products are produced (Bekuma and Galmessa, 2018).

Cattle farming, as said earlier, needs production systems; however, these production systems are faced with so many challenges as a result of persistent economic instability and shortage of man power that can oversee the systems (Kannadhasan et al., 2018; Savalia et al., 2019), thereby resulting in unforeseen increase in gap between the demand and supply of the products. Cattle's health and welfare can be improved simply by proper monitoring of individual cattle, and this in return can add to the strength of the farmers for more sustainable systems that can help in achieving goals of production. One of the various ways of bridging the gap between the cattle and the producers in the expanding systems is by providing applicable solutions for precision livestock farming (Petrović et al., 2024).

Even though there are much challenges involved, the introduction of technologies as solution to many agricultural problems has enable free-flow communication between animals and farmers (Teixeira et al., 2020; Kallioniemi et al., 2024). It is possible to interpret the behavior and health status of individual cattle by the use of sensor-based devices, whereby necessary data and information can be gathered in real time that will assist farmers in decision making should there be any problems (Carpentier et al., 2018; Bello and Moradeyo, 2020). The outcome of this technological arrangement is a judicious utilization of available resources by the farmers for the management of their livestock (Wang et al., 2020; Dos Santos et al., 2021).

Example of the technological arrangement in precision livestock farming is the application of computer vision in different systems for managing livestock with great assurance of its ability to move forward, the practices and vision of livestock farming at low cost (Siegford and Wurtz, 2021). A number of tasks involving livestock management have been made possible with the use of computer vision. These tasks include automatic tracking and counting of cattle (Shao et al., 2020; Bello and Oladipo, 2024), cattle image segmentation, recognition and identification of cattle (Bello et al., 2021a; Bello et al., 2021b; Lee and Seo. 2021), cattle behavior monitoring (Halachmi et al., 2019; Poulopoulou et al., 2019; Dutta et al., 2020; Lee and Seo. 2021; Bello et al., 2022; Alipio and Villena, 2023), cattle body weight measurement (Kamchen et al., 2021), detection of lameness and other related diseases (Dutton-Regester et al., 2018; Ramanoon et al., 2018; Afonso et al., 2020). The wide acceptance of computer vision techniques in precision livestock farming by the livestock community is a proof that the techniques have gradually replaced the casual methods of livestock farming, thereby providing improved environment for livestock and their wellbeing.

2. CATTLE DATASETS FOR COMPUTER VISION TASKS

All over the world and for several decades, research in computer vision applications to livestock has been a welcome development by scientists, thereby leading to some technologies transitioning into moneymaking products (Sahu et al., 2019; Bogueva et al., 2023). The general idea derived from applying computer vision to cattle production systems is to support the routine farming operations which by so doing enables farm workers optimization (Shao et al., 2020; Bello and Oladipo, 2024). Image processing and computer vision tasks such as object detection, image classification, instance segmentation, semantic segmentation, tracking, and pose estimation can be a good source of information for solving a particular problem in a typical cattle farm set up as shown in Figure 1 and Figure 2.

There are great similarities between instance segmentation and semantic segmentation; according to He et al. (2017), while instance segmentation does not only assign class labels but also distinguishes between different instances of the same class, semantic segmentation can only assign a class label to each pixel in the image. Image classification is all about classifying the detected and segmented objects in an image resulting from either instance or semantic segmentation tasks.

Object detection, by using detecting algorithms, detects target objects and their locations in an image, and in so doing, typically leverage machine learning or deep learning to produce meaningful results. Tracking in computer vision means the monitoring of the activities of objects in continuous frames in a video driven by changes of geometric features of individual objects and by taking an initial set of object detections and develops a unique identification for each of the initial detections and then tracks the detected objects as they move around frames in the video, whereby the extraction of object activity trajectories is made possible.

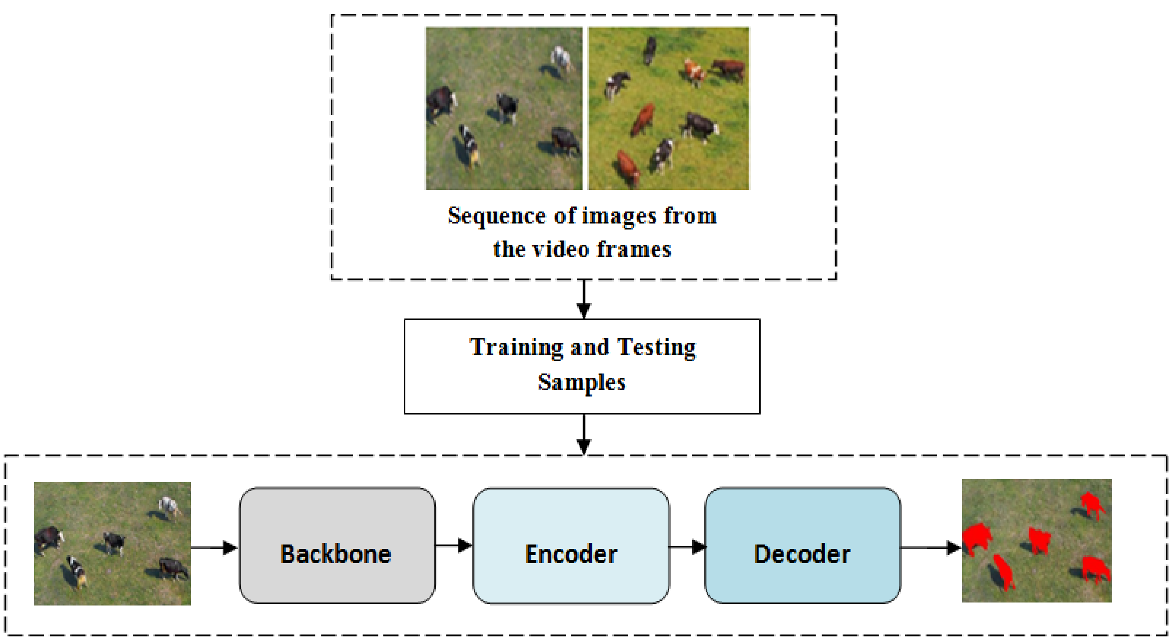

Figure 1. Flow diagram of the computer vision application to cattle detection and counting (Bello and Oladipo, 2024)

Datasets for computer vision tasks should be dependable, that is, it should be tested and trusted, and the experiments in which they are used must yield robust results. All these conditions are prerequisites of datasets acquired for computer vision tasks and experiment. The datasets are used for evaluating algorithms and models' performance in terms of accuracy, effectiveness, efficiency, and robustness (Wang et al., 2020). However, currently, the available datasets for conducting research in precision livestock farming are either small in quantity or low in quality. This, in no small measure, has thwarted the farmers' expectations and advancement of computer vision.

The datasets employ for computer vision tasks fall basically into two major types, namely training dataset and testing dataset. The datasets are gradually becoming publicly available scientific materials, and are majorly employed for the following tasks, namely instance and semantic segmentations, and image classification, object detection and tracking (Figure 1 and Figure 2). This is necessary, in order to relatively develop scientific models for conducting research that can tackle the challenges aforementioned.

Advancing traditional cattle farming to computer vision-based precision cattle farming comes with challenges as challenges and technological developments are inseparable. In addition, challenges are notable with big data as emergence of big data has led to the challenges attributed to various data types (De Alwis et al., 2022).

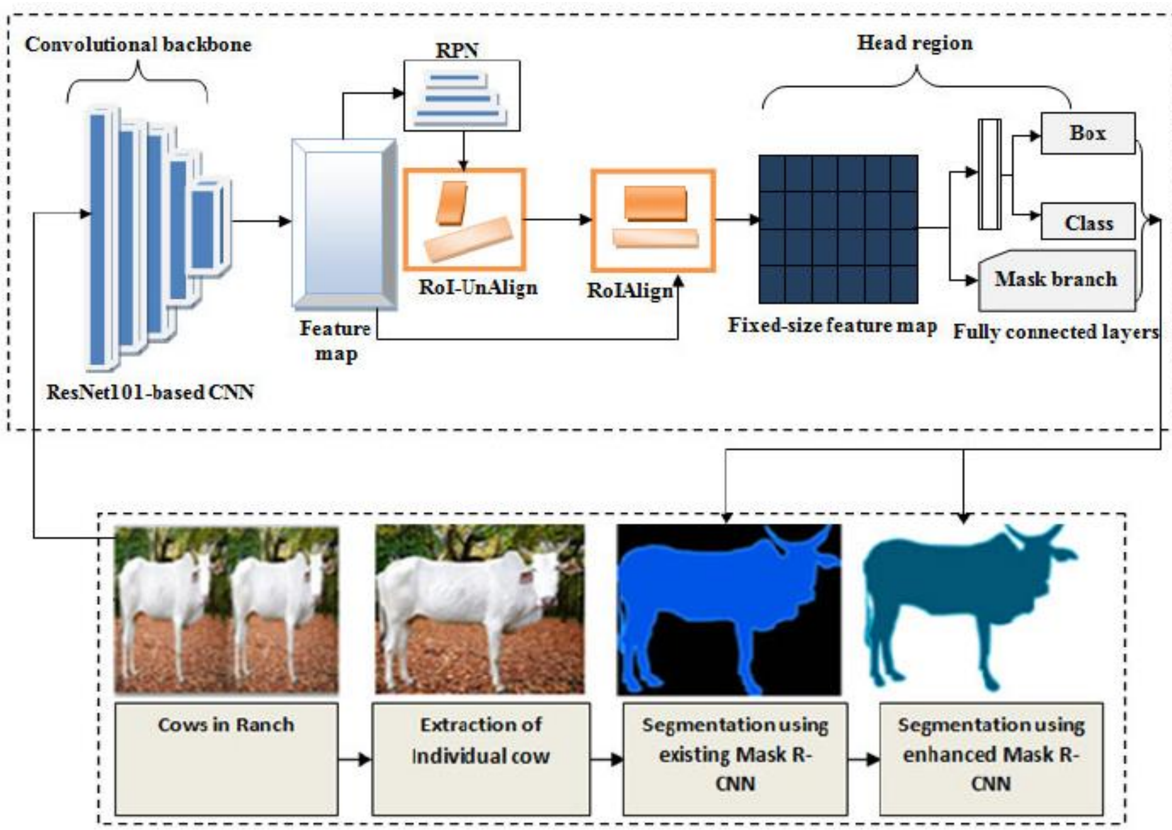

Figure 2. Structural framework of computer vision based enhanced Mask R-CNN for cattle image instance segmentation (Bello et al., 2021a).

The several main challenges in computer vision-based precision livestock farming are as follows.

(1) Lack of tested and trusted generalized methods (models) employ in conducting research and experiment on new datasets: In computer vision applications, it is essential to generalize trained models to strange datasets or different animal species. However, due to generalization gap in computer vision, it is a herculean task to test a trained model with new datasets for computer vision problems. This is a challenge in computer vision-based precision livestock farming.

(2) Unavailability of reliable public datasets: In computer vision and deep learning, availability of datasets in their large quantity is required for accurate models training tasks depending on the problems being addressed and results expected (Kamilaris and Prenafeta-Boldu, 2018). Random image cropping and other different data augmentation approaches have been applied in literatures to add to the number of training images including their labels (Qiao et al., 2020). Some instances of datasets made publicly available are of high quality, and some are of low quality; e.g., MS COCO datasets provided by Microsoft that is comparatively competing with other datasets such as PASCAL Visual Object Classes, ImageNet, and SUN datasets in terms of instances per category.

In addition, the number of instances that are labeled per image with the purpose to aid in contextual information learning is also an important factor that differentiates the MS COCO cattle datasets from other datasets. Because MS COCO datasets are primarily developed for the detection and segmentation of objects that occur in their natural context, this makes MS COCO datasets look competitive. However, there are non-iconic (difficult) images with partial occlusion contained in MS COCO cow datasets which make training difficult as a result of noise and pollution that affected the learned model so much so that it cannot yield accurate results with such unstable appearance. Also, more contextual reasoning is required to recognize the cattle images in the MS COCO datasets because they are smaller.

(3) Problem of available data being non-linear: Regression problems cannot be described adequately using linear models as many real-world problems are non-linear problems. In such scenarios, there are no suitable models better than non-linear models with non-linear functions for the description. In computer vision-based precision livestock farming, it is a great challenge to provide solutions to non-linear problems with scarce resources using appropriate algorithms.

(4) Challenge of acquiring real-time data to support decision making: Acquisition and timely utilization of real-time data for decision support systems which cut across the following support systems (a) Morphological measures, (b) Physiological measures and (3) Phenological measures support systems could pose a challenge in computer vision-based precision livestock farming (Rojo-Gimeno et al., 2019). Animal such as cattle's physiological nature allows them to move voluntarily but without volition. Occasionally, due to sensitivity of cattle to health challenges as living things, real-time data and decision support system are needed by farmers for decision making and for health/welfare monitoring and productivity of the livestock. In addition, accuracy is a factor to consider when acquiring real-time data and system to support decision making for maximum benefit (Kim et al., 2023).

However, there is little or no reliability in the data acquired through these media because the skills that are needed for administering how such data are reposited and transmitted publicly are inadequate (Kamilaris and Prenafeta-Boldú, 2018), thereby mitigating data accuracy. In order to achieve the goals of computer vision-based precision livestock farming and mitigate the aforementioned challenges, there is a need to provide a simplified GUI (graphical user interface) and genuine repository.

(5) Overfitting: A model is said to overfit whenever any techniques of machine learning such as SVMs regression technique that is capable of fitting data that are meant for training perfectly cannot do otherwise, thereby worsening the prediction accuracy on data that are meant for testing than it does on data that are meant for training. SVMs have more notable challenges among which is complexity in the interpretation of the SVMs regression in comparison with more techniques that are interpretable by experts in the domain of precision livestock farming even as SVMs are employed by more animal researchers for different computer vision tasks.

(6) Environmental factors: Climate, light, pollutants, water, food, population density, parasites, and sound among others are important environmental factors to put into consideration when setting up computer vision-based precision livestock farming because they can adversely affect the cattle farming and their management. For example, inability to predict or control climatic conditions can also lead to unpredictable or uncontrollable rain or drought. This also applies to other environmental factors abovementioned as well as socio-economic challenges such as data ownership claim.

(7) Expertise: Competent hands are needed in cattle farming to manage it. Additionally, skillfulness by virtue of possessing special and relevant knowledge and experience appropriate for specific work conditions is a challenge in the computer vision-based precision livestock farming (Kidanemariam and Fesseha, 2020; Chamberlain, 2023). More challenges are as follows; for example, the challenges of converting the findings got from the research into practicable and economical solutions. Moreover, multiple computer vision tasks such as tracking, detection, segmentation and classification are employed in problems involving animal research (Chamberlain, 2023).

Multiple algorithms are most often integrated into systems designed for animal tracking, detection, segmentation, classification, and identification to mention but a few tasks using a video stream (Li et al., 2022). However, cattle farming in recent years has suffered great setback due to lack of computer vision-based cattle management systems for managing the cattle. This kind of arrangement is important for advancement of different application areas of computer vision (Li et al., 2022). Most often, accurate translation is needed of what an organism looks like as a consequence of the interaction of its genotype and the environment; and this translation can better be achieved by interdisciplinary team work for improved precision cattle farming.

As found in several studies on interpretation of animal responses to their environment, the wellbeing and health status of cattle can be monitored by their behavioral reactions to feeding and feeding positions, e.g. lying down and standing (Chapa et al., 2020; Bello et al. 2022). However, via application of computer vision, an interpretation worthy of reliability can be ascribed to the many lingering problems of identifying an organism as a result of its genotype interacting with the environment (Li et al., 2020). In most research that involves animal, there is a wide gap in knowledge between computer vision and its applications to cattle production. Among the several computer vision tasks in animal research, such as detection, segmentation, identification, recognition and classification; only few literatures address cattle farming and the many challenges in its practice using one or multiple methods abovementioned.

In Tassinari et al. (2021), for example, machine vision techniques were applied in the following tasks involving cattle, namely identification, weight estimation, disease detection, behavior monitoring, feeding rate, etc. Some of these tasks required integration of two or more techniques of the computer vision, which are detection, segmentation and classification. Extraction of the cattle features helps in separating the cattle from the background during the conduct of experiment. All the tasks abovementioned should be conducted with precision especially when it involves video experiment, for accurate screen analysis. The aforementioned problems can be addressed and possible solutions provided for a renewed practice of cattle production system.

Observation is the aggregate of the responses, reactions or movements made by an organism in any situation; so, behavior, being one of the parametric tools employed by farmers to determine the status of their livestock, is one area in which computer vision is applied for cattle behavior analysis. By mere physical observation, an expert can deduce different variety of stimuli from individual cattle such as morphological stimuli and phenotypical stimuli. This kind of observation and information, within the reach of farmers, can be a good start towards managing the welfare and production of cattle. According to Berckmans (2017), precision livestock farming is any of the state-of-the-art techniques applied by farmers to manage and monitor individual animals' welfare and performance in terms of production and reproduction. This can only be made possible with the synergy of state-of the-art techniques and livestock farm management systems (Bello and Moradeyo, 2023).

3. OPPORTUNITIES OF COMPUTER VISION IN CATTLE FARMING

There are several opportunities in applying computer vision to cattle farming and management. Being performed manually has made the tasks involved in traditional method of cattle farming labor intensive, costly and time-consuming exercise. This and many other challenges and risks involved in practicing the traditional method as found in nomadic method where herdsman changes locations regularly as required for food for animal life sustenance can be overcome completely with the applications of computer vision to livestock farming, thereby improving cattle's health and welfare (Bello and Moradeyo, 2023). Worthy of discussion are the several opportunities of future research in computer vision-based precision livestock farming that are of interest to farmers and research community.

(1) Mixing different species or varieties of cattle: In computer vision-based precision livestock farming, different species or varieties of animals such as cattle can be mixed and thus produce their hybrids. There is an established fact that each individual cattle possess its own benefits, and mixing the modalities of the cattle different species and varieties will not only lead to an overall improvement in term of performance, it can have progressive influence on cattle's life cycle in the aspect of morphology, physiology and phenology, thereby increasing their productivity and immunity against diseases.

(2) Opportunity of interdisciplinary synergy: With computer vision-based precision livestock farming, the tendency for interdisciplinary synergy is high with great impact on labor efficiency. There is more to gain by interdisciplinary synergy among which are reduction in cost of farming, labor efficiency, knowledge sharing, big data and professional tools accessibility such as open datasets and Internet-of-Things using sensors to get the cattle's body feature parameters such as size and shape. Moreover, with computer vision-based precision livestock farming, there is an interdisciplinary incorporation of different branches of knowledge for managing the farm heuristically, whereby individual farmer and researcher are enlightened to get information independently for maintaining awareness and avoidance of any bias.

(3) Nonsubjective live weight estimation: As the reproductive potential of a species is its relative capacity to reproduce itself under optimal conditions, in most cases, to determine the rate of reproduction in cattle, from fertility (normal/abnormal) to lactation, and their respiratory rate (Wu et al., 2020). weight estimations are commonly employed. Oftentimes, state-of-the-art and other management methods of estimating live weight are unreliable and inaccurate to give true live weight of the cattle. Therefore, worthy of future research are 1) What it takes (cost) to acquire the tools employed for weight estimation, 2) The time consumption, 3) The installation and application with the technical-know-how involved, and 4) The stress and injury they cause to the cattle.

Although estimation of some morphological traits can be used to estimate the weight of the cattle based on 2D/3D sensors (Hansen et al., 2018), however, whenever camera is used in capturing the body features of the cattle, there is tendency for the camera viewpoints to influence the extracted features, thereby leading to inaccurate estimation of the cattle live weight. Therefore, objective approach should be devised and preferred for estimating live weight to the subjective approach which can be easily manipulated by the individuals.

4. CONCLUSIONS

We have presented an overview of the computer vision-based precision livestock farming by looking into the challenges and possible directions for future research opportunities. For a computer vision-based precision livestock farming, there is a need for synergy of computer vision and state-of-the-art technologies, this is in addition to pooling of dependable datasets and making the datasets publicly available. Moreover, only tested and trusted scientific methods should be employed in carrying out experiment with the datasets. This is to strengthening the experimental procedures, results and evaluations. Conclusively, any obstruction that can slow down or impede actualizing the computer vision-based cattle farming operations needs to be tackled at all cost not only for the advancement of industrial applications but also for commercial opportunities. Worthy of future study are the following; (a) Strategy for overcoming all the raised challenges, (2) Contributory factors to farmers' lukewarm attitude towards computer vision-based precision livestock farming.

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