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92. Reducing annotation dependency in automated rumen-fill scoring through pairwise comparisons and curvature analysis

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Implications

Rumen-fill is a valuable indicator of feed intake and is useful for early health alerts. Manual assessment across large herds is impractical and delays diagnosis. Automation using 3D imaging offers consistency and scalability but faces challenges of subjective traditional scoring systems and relies on extensive annotated data. If we can show that the geometry of the paralumbar fossa correlates with rumen fill, while making annotations more robust against bias, we could easily scale automated rumen-fill scoring without relying on troves of annotations. Results in the first stage indicate that the concavity of the paralumbar fossa from 3D images moderately correlates ($r = -0.46$, $P = 0.002$) with rumen-fill. This suggests that curvature can inform rumen-fill status and enhance automated scoring methods.

Introduction

Rumen fill is an indicator of cows' feed and water intake (Hogan and Phillips, 2008). As it fluctuates daily, it is only informative if assessed regularly; a punctual low rumen might simply reflect the time since the last meals, while steadily low feed intake can be indicative of other health issues (Burfeind et al., 2010). Visually assessing rumen-fill across an entire herd is impractical. 3D imaging can support proactive health management through regular and scalable rumen-fill evaluations (Song et al., 2019). Nonetheless, developing automated scoring methods faces challenges, notably the necessary quantity and diversity of annotated data. Rumen-fill is scored according to a five-point scale (Burfeind et al., 2010). This scale was developed for visual assessments in clinical practice, not for machine-learnability, and the points may not exactly reflect the quantitative geometry of the paralumbar fossa. Drawing on parallel developments in automated lameness scoring (which also uses a five-point scale and faces similar challenges of scalability and observer inconsistencies), we test a comparative method to rank rumen-fill states by comparing individuals against each other, instead of assigning them discrete scores (Sheng et al., 2023). We then compare the rumen-fill rank of each image against

Methods

Recordings of the left paralumbar fossa were obtained with a 3D Camera (D435i, Intel RealSense Technology) generating aligned channels for BGR (Blue, green and red) and depth along with 3 dimensional acceleration. Images were recorded handheld over the paralumbar fossa at 30 fps. A custom YOLO-v8 model was trained to predict the location of the paralumbar fossa using 856 annotated images. Annotation guidelines were to use the jointure of the last rib to the vertebrae as a left bound, the hook bone as a right bound and the point where the right edge of the external abdominal oblique muscle meets the last rib as lower bound. Examples of annotations are found on the right panes of Figure 1. Frame motion was estimated as the acceleration magnitude calculated by taking the square root of the sum of the squares of the x, y, and z acceleration components from the camera's accelerometer. The location of the paralumbar fossa was predicted on the RGB channel using the model, and the depth channel was cropped to the extent of the predicted bounding box.

Curvature was calculated on the cropped depth channel. Gradients (first and second derivatives) in the X and Y directions were computed using the Sobel operator and a kernel size of 3. The gradient magnitude was determined as the square root of the sum of the squares of the first x and y gradients. The Laplacian approximation of the second derivative across both axes was computed as the sum of the second derivatives in the x and y directions. Curvature was estimated using the formula: $Curvature = \frac{Laplacian}{(1 + Gradient\ Magnitude^2)^{\frac{3}{2}}}$. Finally, concavity is calculated by summing the positive differences between the mean curvature and each 3-pixel kernel's curvature.

For each recording, a single frame was selected for annotating. This frame was chosen based on having the least motion among those frames where the bounding box confidence exceeded 0.8. Instead of assigning a discrete score (1–5) to each image, observers compared 36 images of paralumbar fossae, organized in 1086 pairs (taken at different times, independent of individual animal) shown side by side. For each pair, they selected the image with the highest rumen fill. The criteria in the flowchart by Schneider et al. (2022) were used to determine the image with the fullest rumen. Images were assigned a score of 1 to 36 using Elo rating on the pairwise comparison rankings and the probability for each image to be selected for highest rumen-fill. Pearson correlation was computed between Elo score and curvature metrics.

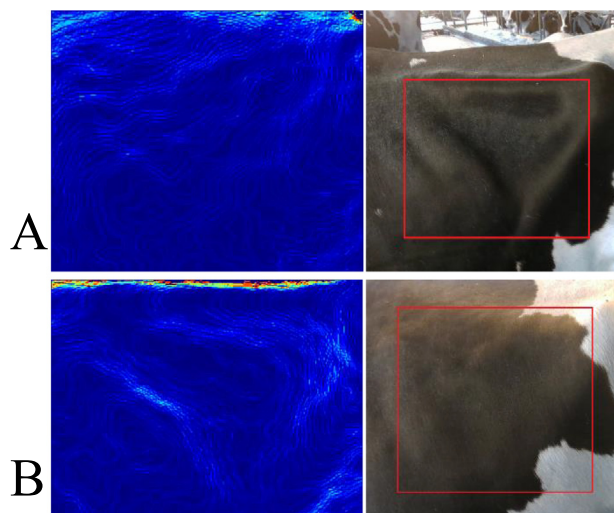


Fig. 1. Curvature maps and BGR image of the upper-left part of the paralumbar in two images classified as having fuller (A) and emptier (B) rumens. Detection of the paralumbar fossa was done with a custom yolo v8 model. The ridges visible on the top and left of the curvature maps correspond to the transversal processes and last rib respectively.

Results

Our findings indicate low to moderate correlations ranging from -0.18 to -0.46 between curvature metrics of the paralumbar fossa and rumen-fill rank. The highest correlation was for total concavity volume ($r = -0.46$, $P = 0.002$). This correlation suggests that concavity in the bounding box is informative of rumen-fill status but not sufficient to reproduce human scores. The correlation between rumen-fill rank and the lower quartile of curvature values was -0.45 ($P = 0.003$) whereas it was only -0.29 with the upper quartile, possibly suggesting that regions of lower curvature are more informative and that future efforts should be focused on identifying regions offering the best correspondence to human observations.

Conclusion and discussion

Since curvature is a measurable attribute rather than an annotated target, the correlation corroborates earlier results (Song et al., 2019) wherein easily accessible numerical values could be indicators of rumen-fill status. If this holds true, then we can circumvent the reliance of rumen-fill scoring algorithms on extensive training data. This method thus provides a step in efficiently automating rumen-fill scoring for implementation in precision health and nutrition monitoring. Refinements are still needed in the segmentation of the paralumbar fossa and identifying features which best correlate with fill to improve agreement with annotations. A previous pilot study had noted that the shape of the paralumbar fossa was affected by movements and particularly step-cycle (Derakhshan and Yousefzadeh, 2024). More standardized images should contribute to more consistent results. A time dimension should also be added to account for reticulo-ruminal contractions (Song et al., 2022).

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