**Deep learning and image processing for high-throughput udder phenotyping in dairy cows**

Udder morphology is associated with performance and is important for genetic improvement in dairy cattle. However, systematic, and large-scale udder phenotyping is labor-intensive. Therefore, this project aims (1) to automate the collection of udder phenotypes from depth images (img), (2) to generate phenotypes from the udder and quarter segments (e.g. teat geodesic distance, circularity, eccentricity, surface area, and volume), and (3) to investigate their association with voluntary milking system (VMS) records (e.g. milk flow, yield, and kick-offs). Videos of the udders of 150 Holstein cows (parity 2.2±1.2, DIM 155 ±103) were recorded at a VMS farm using a RealSense D455 depth camera at 30 fps. Images from 50 cows were incorporated into a larger dataset used to train (Tr) and test (Te) convolutional neural networks (CNN; YOLOV8) for classification, segmentation, and keypoint detection. The classifier (Tr=14,164; Te=4,778 img), trained to select images without occlusion, had an F1-score of 0.91. The segmenter (Tr=2,178; Te=725 img) had an intersection over union of 0.93±0.03 on the udder region. The keypoint model (Tr=14,164; Te=4,778 img) predicted teat locations with error (%; distance/udder diagonal) of 5.7±3.8 left front, 4.6±3.8 right front, 5.2±4.1 left rear, and 6.1±4.7 right rear. The Watershed algorithm was used to segment the udder into quarters, and a second classifier was trained to discard incorrect results (recall=0.87±0.12, precision=0.56±0.04, k=5 folds, 300 img). The CNN models were used to get image class, udder region, and teat locations from images of the remaining 100 cows and unannotated images. Udder phenotypes were extracted from all non-discarded images (170±191 img/cow, 138 cows), and the median was used for correlation analysis. Udder surface area was correlated with session yield (r=0.53, p<0.01) and highest yield of current lactation (r=0.48, p<0.01), and front teat geodesic distance with session yield (r=0.41, p<0.01). Deep learning and image processing accurately produced large-scale udder morphology traits. Associations of the image derived traits with performance and genetics should be investigated.

Keywords: udder phenotyping, depth images