ESTIMASI BERAT BADAN SAPI PADA GAMBAR MONOKULAR MENGGUNAKAN FITUR BERBASIS RASIO TUBUH DAN *FULLY CONNECTED NEURAL NETWORK* (FCNN)

SKRIPSI

Diajukan sebagai syarat untuk memperoleh gelar Sarjana Komputer
Program Studi Ilmu Komputer

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Sebuah skripsi yang diajukan untuk memenuhi salah satu syarat memperoleh gelar Sarjana Komputer pada Fakultas Pendidikan Matematika dan Ilmu Pengetahuan Alam

ESTIMASI BERAT BADAN SAPI PADA GAMBAR MONOKULAR MENGGUNAKAN FITUR BERBASIS RASIO TUBUH DAN *FULLY CONNECTED NEURAL NETWORK* (FCNN)

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LEMBAR PERNYATAAN

Dengan ini, saya menyatakan bahwa skripsi berjudul "Estimasi Berat Badan Sapi pada Gambar Monokular Menggunakan Fitur Berbasis Rasio Tubuh dan *Fully Connected Neural Network* (FCNN)" beserta seluruh isinya merupakan hasil karya saya sendiri. Saya tidak melakukan penjiplakan maupun pengutipan dengan cara yang melanggar etika keilmuan yang berlaku di lingkungan akademik. Atas penyataan ini, saya bersedia menerima segala risiko atau sanksi jika di kemudian hari ditemukan pelanggaran terhadap etika keilmuan atu adanya klaim dari pihak lain terkait keaslian karya ini.

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Yang Membuat Pernyataan,

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Penulis menyadari bahwa skripsi ini masih memiliki kekurangan. Oleh karena itu, penulis membuka diri terhadap kritik dan saran yang membangun sebagai bahan perbaikan di masa depan. Semoga skripsi ini dapat memberikan manfaat di bidang teknologi informasi dan manajemen pengetahuan, serta menjadi referensi bagi penelitian selanjutnya.

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ESTIMASI BERAT BADAN SAPI PADA GAMBAR MONOKULAR MENGGUNAKAN FITUR BERBASIS RASIO TUBUH DAN *FULLY CONNECTED NEURAL NETWORK* (FCNN)

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ABSTRAK

Estimasi berat badan sapi dari data visual menawarkan alternatif tanpa kontak terhadap metode penimbangan tradisional, dengan potensi meningkatkan efisiensi dan kesejahteraan hewan dalam manajemen peternakan. Penelitian ini mengeksplorasi pendekatan tiga tahap yang meliputi segmentasi siluet sapi dari citra RGB, ekstraksi fitur berbasis rasio melalui *image processing*, dan regresi menggunakan *Fully Connected Neural Network* (FCNN). *Mask* hasil segmentasi digunakan untuk menghasilkan fitur berbasis rasio, sementara integrasi dengan fitur *Histogram of Oriented Gradients* (HOG) juga dievaluasi melalui arsitektur paralel. Model segmentasi menunjukkan performa tinggi dengan nilai MIoU sebesar 0.96, menegaskan keandalannya dalam mengekstraksi siluet sapi. Namun, tahap regresi menghasilkan performa terbatas, di mana model FCNN terbaik tanpa HOG mencapai RMSE 31.82 kg, MAPE 16.51%, dan R^2 0.247. Perbandingan dengan beberapa model *baseline* sederhana menunjukkan hasil yang sebanding, dengan regresi linear sedikit lebih baik, sehingga mengindikasikan keterbatasan utama berasal dari fitur yang digunakan, bukan dari arsitektur model. Penelitian selanjutnya disarankan untuk mengeksplorasi representasi fitur yang lebih informatif, seperti fitur jenis ras sapi, representasi visual langsung dengan CNN, atau fitur morfologi tubuh yang lebih detail guna meningkatkan akurasi estimasi berat sapi berbasis citra.

Kata kunci: ***Fully Connected Neural Network (FCNN), Estimasi Berat Sapi, Computer Vision, Machine Learning***

CATTLE WEIGHT ESTIMATION FROM MONOCULAR IMAGES USING BODY RATIO-BASED FEATURES AND FULLY CONNECTED NEURAL NETWORK (FCNN)

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ABSTRACT

Estimating cattle body weight from visual data offers a contactless alternative to traditional weighing methods, with the potential to improve efficiency and animal welfare in farm management. This study explores a three-stage approach consisting of cattle silhouette segmentation from RGB images, ratio-based feature extraction through image processing, and regression using a Fully Connected Neural Network (FCNN). Segmentation masks were used to generate ratio-based features, while integration with Histogram of Oriented Gradients (HOG) features was also evaluated through a parallel architecture. The segmentation model achieved high performance with an MIoU of 0.96, confirming its reliability in extracting cattle silhouettes. However, the regression stage yielded limited performance, with the best FCNN model without HOG reaching an RMSE of 31.82 kg, MAPE of 16.51%, and R^2 of 0.247. Comparisons with several simple baseline models showed comparable results, with linear regression performing slightly better, indicating that the primary limitation lies in the features used rather than the model architecture. Future research is recommended to explore more informative feature representations, such as cattle breed, direct visual representations using CNN, or more detailed morphological body features to improve image-based cattle weight estimation accuracy.

Keyword: ***Fully Connected Neural Network (FCNN), Cattle Weight Estimation, Computer Vision, Machine Learning***

DAFTAR ISI

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DAFTAR PUSTAKA

Abera, M., Yusuf Mummed, Y., Eshetu, M., Pilla, F., & Wondifraw, Z. (2021). Physiological, biochemical, and growth parameters of fogera cattle calves to heat stress during different seasons in sub-humid part of ethiopia. *Animals*, *11*(4), 1062. https://doi.org/10.3390/ani11041062

Adinata, Y., Noor, R. R., Priyanto, R., Cyrilla, L., & Sudrajad, P. (2023). Morphometric and physical characteristics of Indonesian beef cattle. *Archives Animal Breeding*, *66*(2), 153–161. https://doi.org/10.5194/aab-66-153-2023

Alzubi, J., Nayyar, A., & Kumar, A. (2018). Machine learning from theory to algorithms: an overview. *Journal of Physics: Conference Series*, *1142*, 012012. https://doi.org/10.1088/1742-6596/1142/1/012012

Ambika. (2023, September 19). *What is computer vision? (history, applications, challenges)*. medium.com. https://medium.com/@ambika199820/what-is-computer-vision-history-applications-challenges-13f5759b48a5

Arias, C. R. (2022). An introduction to artificial intelligence. Dalam M. J. Paulus & M. D. Langford (Ed.), *AI, faith, and the future: an interdisciplinary approach* (hlm. 15–51). Pickwick Publications.

Bai, L., Guo, C., & Song, J. (2025). Cattle weight estimation model through readily photos. *Engineering Applications of Artificial Intelligence*, *143*, 109976. https://doi.org/10.1016/j.engappai.2024.109976

Bandyopadhyay, H. (2022, Juni 9). *What is computer vision? [basic tasks & techniques]*. https://www.v7labs.com/blog/what-is-computer-vision

Benalcázar, M. E. (2019). Machine learning for computer vision: a review of theory and algorithms. *Revista Ibérica de Sistemas e Tecnologias de Informação*, *E19*, 608–618.

Bengio, Y. (2009). Learning deep architectures for AI. *Foundations and Trends® in Machine Learning*, *2*(1), 1–127. https://doi.org/10.1561/2200000006

Bhatt, D., Patel, C., Talsania, H., Patel, J., Vaghela, R., Pandya, S., Modi, K., & Ghayvat, H. (2021). CNN cariants for computer vision: history, architecture, application, challenges and future scope. *Electronics*, *10*(20), 2470. https://doi.org/10.3390/electronics10202470

Biederman, I. (1985). Human image understanding: recent research and a theory. *Computer Vision, Graphics, and Image Processing*, *32*(1), 29–73. https://doi.org/10.1016/0734-189X(85)90002-7

Brown, G. (2011). Ensemble learning. Dalam *Encyclopedia of Machine Learning* (hlm. 312–320). Springer US. https://doi.org/10.1007/978-0-387-30164-8_252

Cang, Y., He, H., & Qiao, Y. (2019). An intelligent pig weights estimate method based on deep learning in sow stall environments. *IEEE Access*, *7*, 164867–164875. https://doi.org/10.1109/ACCESS.2019.2953099

Chawatama, R. T. T., & Shaowei, S. (2021). Artificial intelligence: the backbone of industry evolution, impact, and future. *International Journal of Science and Research (IJSR)*, *10*(5), 1130–1137. https://doi.org/10.21275/SR21518092101

Chen, L. (2019, Januari 3). *Basic ensemble Learning (random forest, AdaBoost, gradient boosting)- step by step explained*. medium.com. https://medium.com/data-science/basic-ensemble-learning-random-forest-adaboost-gradient-boosting-step-by-step-explained-95d49d1e2725

Cominotte, A., Fernandes, A. F. A., Dorea, J. R. R., Rosa, G. J. M., Ladeira, M. M., van Cleef, E. H. C. B., Pereira, G. L., Baldassini, W. A., & Machado Neto, O. R. (2020). Automated computer vision system to predict body weight and average daily gain in beef cattle during growing and finishing phases. *Livestock Science*, *232*, 103904. https://doi.org/10.1016/j.livsci.2019.103904

Das, S., Dey, A., Pal, A., & Roy, N. (2015). Applications of artificial intelligence in machine learning: review and prospect. *International Journal of Computer Applications*, *115*(9), 31–41. https://doi.org/10.5120/20182-2402

Dhage, S. N., & Raina, C. K. (2016). A review on machine learning techniques. *International Journal on Recent and Innovation Trends in Computing and Communication*, *4*(3), 395–399. https://doi.org/https://doi.org/10.17762/ijritcc.v4i3.1902

Dohmen, R., Catal, C., & Liu, Q. (2022). Computer vision-based weight estimation of livestock: a systematic literature review. *New Zealand Journal of*

Agricultural Research, *65*(2–3), 227–247. https://doi.org/10.1080/00288233.2021.1876107

Escott, E. (2017, Oktober 24). *What are the 3 types of AI? A guide to narrow, general, and super artificial intelligence*. codebots.com. https://codebots.com/artificial-intelligence/the-3-types-of-ai-is-the-third-even-possible

Feng, T., Guo, Y., Huang, X., & Qiao, Y. (2023). Cattle target segmentation method in multi-scenes using improved DeepLabV3+ method. *Animals*, *13*(15), 2521. https://doi.org/10.3390/ani13152521

Fernandes, A. F. A., Dórea, J. R. R., Fitzgerald, R., Herring, W., & Rosa, G. J. M. (2019). A novel automated system to acquire biometric and morphological measurements and predict body weight of pigs via 3D computer vision. *Journal of Animal Science*, *97*(1), 496–508. https://doi.org/10.1093/jas/sky418

Frederick Adzitey. (2011). Effect of pre-slaughter animal handling on carcass and meat quality. *International Food Research Journal*, *18*(2), 485–491.

Ginsberg, Matt. (2012). *Essentials of artificial intelligence*. Elsevier Science.

Gjergji, M., de Moraes Weber, V., Otavio Campos Silva, L., da Costa Gomes, R., Luis Alves Campos de Araujo, T., Pistori, H., & Alvarez, M. (2020). Deep learning techniques for beef cattle body weight prediction. *2020 International Joint Conference on Neural Networks (IJCNN)*, 1–8. https://doi.org/10.1109/IJCNN48605.2020.9207624

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M., & Toulmin, C. (2010). Food security: the challenge of feeding 9 billion people. *Science*, *327*(5967), 812–818. https://doi.org/10.1126/science.1185383

Guo, Y., Liu, Y., Oerlemans, A., Lao, S., Wu, S., & Lew, M. S. (2016). Deep learning for visual understanding: a review. *Neurocomputing*, *187*, 27–48. https://doi.org/10.1016/j.neucom.2015.09.116

Haenlein, M., & Kaplan, A. (2019). A brief history of artificial intelligence: on the past, present, and future of artificial intelligence. *California Management Review*, *61*(4), 5–14. https://doi.org/10.1177/0008125619864925

Hansen, M. F., Smith, M. L., Smith, L. N., Abdul Jabbar, K., & Forbes, D. (2018). Automated monitoring of dairy cow body condition, mobility and weight using a single 3D video capture device. *Computers in Industry*, *98*, 14–22. https://doi.org/10.1016/j.compind.2018.02.011

Hasan, F. M., Thomson, P. C., Islam, M. R., Clark, C. E. F., Chlingaryan, A., & Lomax, S. (2024). Monitoring cattle liveweight using a mobile, in-paddock weigh platform: validation, attendance and utility. *Smart Agricultural Technology*, *9*, 100639. https://doi.org/10.1016/j.atech.2024.100639

Hayashi, C. (1998). What is data science ? fundamental concepts and a heuristic example. Dalam *Data Science, Classification, and Related Methods* (hlm. 40–51). Springer. https://doi.org/10.1007/978-4-431-65950-1_3

He, H., Qiao, Y., Li, X., Chen, C., & Zhang, X. (2021). Optimization on multi-object tracking and segmentation in pigs' weight measurement. *Computers and Electronics in Agriculture*, *186*, 106190. https://doi.org/10.1016/j.compag.2021.106190

IBM. (t.t.). *What is image segmentation?* ibm.com. Diambil 30 April 2024, dari https://www.ibm.com/think/topics/image-segmentation

Irfan Said, M. (2022). The Role of the livestock farming industry in supporting the global agricultural industry. Dalam *Agricultural Development in Asia - Potential Use of Nano-Materials and Nano-Technology*. IntechOpen. https://doi.org/10.5772/intechopen.97868

Jardim, C. C., Silveira, I. D. B., Restle, J., Mendonça, F. S., Bethancourt-Garcia, J. A., Oliveira, R. M. de, Moares, R. E. de, Reis, N. P., & Vaz, R. Z. (2022). Effect of good handling on stress indicators and behaviour in beef cattle. *Semina: Ciências Agrárias*, *43*(6), 2517–2530. https://doi.org/10.5433/1679-0359.2022v43n6p2517

Jordan, J. (2018, Mei 30). *Evaluating image segmentation models*. jeremyjordan.me. https://www.jeremyjordan.me/evaluating-image-segmentation-models/

Jun, K., Kim, S. J., & Ji, H. W. (2018). Estimating pig weights from images without constraint on posture and illumination. *Computers and Electronics in Agriculture*, *153*, 169–176. https://doi.org/10.1016/j.compag.2018.08.006

Le Cozler, Y., Allain, C., Xavier, C., Depuille, L., Caillot, A., Delouard, J. M., Delattre, L., Luginbuhl, T., & Faverdin, P. (2019). Volume and surface area of holstein dairy cows calculated from complete 3D shapes acquired using a high-precision scanning system: interest for body weight estimation. *Computers and Electronics in Agriculture*, *165*, 104977. https://doi.org/10.1016/j.compag.2019.104977

LeCun, Y., Bengio, Y., & Hinton, G. (2015). Deep learning. *Nature*, *521*(7553), 436–444. https://doi.org/10.1038/nature14539

Li, X., Wu, J., Zhao, Z., Zhuang, Y., Sun, S., Xie, H., Gao, Y., & Xiao, D. (2023). An improved method for broiler weight estimation integrating multi-feature with gradient boosting decision tree. *Animals*, *13*(23), 3721. https://doi.org/10.3390/ani13233721

Liu, Y., Wang, Y., & Zhang, J. (2012). New machine learning algorithm: random forest. Dalam *Information Computing and Application* (hlm. 246–252). Springer. https://doi.org/10.1007/978-3-642-34062-8_32

Lopes, M. A., Vieira, J. A., Lima, F. H. S. de, Demeu, F. A., Bruhn, F. R. P., Pereira, A., Vicente, F. H., & Casas, P. S. (2018). Technical and economic efficiency of bovine weighing methods. *Semina: Ciências Agrárias*, *39*(3), 1167. https://doi.org/10.5433/1679-0359.2018v39n3p1167

Los, S., Mücher, C. A., Kramer, H., Franke, G. J., & Kamphuis, C. (2023). Estimating body dimensions and weight of cattle on pasture with 3D models from UAV imagery. *Smart Agricultural Technology*, *4*, 100167. https://doi.org/10.1016/j.atech.2022.100167

Mardhati, M., González, L. A., Thomson, P. C., Clark, C. E. F., & García, S. C. (2021). Short-term liveweight changes of dairy cows measured by stationary and walk-over weighing scales. *Journal of Dairy Science*, *104*(7), 8202–8213. https://doi.org/10.3168/jds.2020-19912

Maulud, D., & Abdulazeez, A. M. (2020). A review on linear regression comprehensive in machine learning. *Journal of Applied Science and Technology Trends*, *1*(2), 140–147. https://doi.org/10.38094/jastt1457

Meer, P. (2004). Robust techniques for computer vision. Dalam *Emerging Topics in Computer Vision* (hlm. 109–183). Prentice Hall.

Mihajlovic, I. (2019, April 26). *Everything you ever wanted to know about computer vision*. medium.com. https://medium.com/data-science/everything-you-ever-wanted-to-know-about-computer-vision-heres-a-look-why-it-s-so-awesome-e8a58dfb641e

Mitchell, T. M. (2006). The discipline of machine learning. *Pittsburgh: Carnegie Mellon University, School of Computer Science, Machine Learning Department*, *9*.

Mollah, Md. B. R., Hasan, Md. A., Salam, Md. A., & Ali, Md. A. (2010). Digital image analysis to estimate the live weight of broiler. *Computers and Electronics in Agriculture*, *72*(1), 48–52. https://doi.org/10.1016/j.compag.2010.02.002

Monteiro, F. C., & Campilho, A. C. (2006). Performance evaluation of image segmentation. *International Conference Image Analysis and Recognition*, 248–259. https://doi.org/10.1007/11867586_24

Najafabadi, M. M., Villanustre, F., Khoshgoftaar, T. M., Seliya, N., Wald, R., & Muharemagic, E. (2015). Deep learning applications and challenges in big data analytics. *Journal of Big Data*, *2*(1). https://doi.org/10.1186/s40537-014-0007-7

Natekin, A., & Knoll, A. (2013). Gradient boosting machines, a tutorial. *Frontiers in Neurorobotics*, *7*. https://doi.org/10.3389/fnbot.2013.00021

Nguyen, A. H., Holt, J. P., Knauer, M. T., Abner, V. A., Lobaton, E. J., & Young, S. N. (2023). Towards rapid weight assessment of finishing pigs using a handheld, mobile RGB-D camera. *Biosystems Engineering*, *226*, 155–168. https://doi.org/10.1016/j.biosystemseng.2023.01.005

Nilchuen, P., Yaigate, T., & Sumon, W. (2021). Body measurements of beef cows by using mobile phone application and prediction of body weight with regression model. *Songklanakarin Journal of Science & Technology*, *43*(6).

Nishide, R., Yamashita, A., Takaki, Y., Ohta, C., Oyama, K., & Ohkawa, T. (2018). Calf robust weight estimation using 3D contiguous cylindrical model and directional orientation from stereo images. *Proceedings of the Ninth International Symposium on Information and Communication Technology*, 208–215. https://doi.org/10.1145/3287921.3287923

Oquab, M., Bottou, L., Laptev, I., & Sivic, J. (2015). Is object localization for free? - weakly-supervised learning with convolutional neural networks. *2015 IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 685–694. https://doi.org/10.1109/CVPR.2015.7298668

Pouyanfar, S., Sadiq, S., Yan, Y., Tian, H., Tao, Y., Reyes, M. P., Shyu, M.-L., Chen, S.-C., & Iyengar, S. S. (2019). A survey on deep learning: algorithms, techniques, and applications. *ACM Computing Surveys*, *51*(5), 1–36. https://doi.org/10.1145/3234150

Pressman, R. S. (2012). *Rekayasa perangkat lunak: pendekatan praktisi* (7 ed.). Andi Offset.

Qiao, Y., Kong, H., Clark, C., Lomax, S., Su, D., Eiffert, S., & Sukkarieh, S. (2021). Intelligent perception for cattle monitoring: a review for cattle identification, body condition score evaluation, and weight estimation. *Computers and Electronics in Agriculture*, *185*, 106143. https://doi.org/10.1016/j.compag.2021.106143

Russell, S. J., & Norvig, Peter. (2016). *Artificial intelligence: a modern approach* (3rd ed.). Pearson.

Samuel, A. L. (1959). Some studies in machine learning using the game of checkers. *IBM Journal of Research and Development*, *3*(3), 210–229. https://doi.org/10.1147/rd.33.0210

Sandler, M., Howard, A., Zhu, M., Zhmoginov, A., & Chen, L.-C. (2018). MobileNetV2: inverted residuals and linear bottlenecks. *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 4510–4520.

Segerkvist, K. A., Höglund, J., Österlund, H., Wik, C., Högberg, N., & Hessle, A. (2020). Automatic weighing as an animal health monitoring tool on pasture. *Livestock Science*, *240*, 104157. https://doi.org/10.1016/j.livsci.2020.104157

Sekaran, U., Lai, L., Ussiri, D. A. N., Kumar, S., & Clay, S. (2021). Role of integrated crop-livestock systems in improving agriculture production and addressing food security – a review. *Journal of Agriculture and Food Research*, *5*, 100190. https://doi.org/10.1016/j.jafr.2021.100190

Smith, J., Sones, K., Grace, D., MacMillan, S., Tarawali, S., & Herrero, M. (2013). Beyond milk, meat, and eggs: role of livestock in food and nutrition security. *Animal Frontiers*, *3*(1), 6–13. https://doi.org/10.2527/af.2013-0002

Snelling, W. M., Thallman, R. M., Spangler, M. L., & Kuehn, L. A. (2022). Breeding sustainable beef cows: reducing weight and increasing productivity. *Animals*, *12*(14), 1745. https://doi.org/10.3390/ani12141745

Song, X., Bokkers, E. A. M., van der Tol, P. P. J., Groot Koerkamp, P. W. G., & van Mourik, S. (2018). Automated body weight prediction of dairy cows using 3-dimensional vision. *Journal of Dairy Science*, *101*(5), 4448–4459. https://doi.org/10.3168/jds.2017-13094

Sousa, R. V., Tabile, R. A., Inamasu, R. Y., & Martello, L. S. (2018). Evaluating a LiDAR sensor and artificial neural network based-model to estimate cattle live weight. *10th International Livestock Environment Symposium (ILES X)*. https://doi.org/10.13031/iles.18-004

Szegedy, C., Wei Liu, Yangqing Jia, Sermanet, P., Reed, S., Anguelov, D., Erhan, D., Vanhoucke, V., & Rabinovich, A. (2015). Going deeper with convolutions. *2015 IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 1–9. https://doi.org/10.1109/CVPR.2015.7298594

Tasdemir, S., Urkmez, A., & Inal, S. (2011). Determination of body measurements on the Holstein cows using digital image analysis and estimation of live weight with regression analysis. *Computers and Electronics in Agriculture*, *76*(2), 189–197. https://doi.org/10.1016/j.compag.2011.02.001

Thapar, G., Biswas, T. K., Bhushan, B., Naskar, S., Kumar, A., Dandapat, P., & Rokhade, J. (2023). Accurate estimation of body weight of pigs through smartphone image measurement app. *Smart Agricultural Technology*, *4*, 100194. https://doi.org/10.1016/j.atech.2023.100194

Wang, S., Li, Q., Peng, J., & Niu, H. (2023). Effects of long-term cold stress on growth performance, behavior, physiological parameters, and energy metabolism in growing beef cattle. *Animals*, *13*(10), 1619. https://doi.org/10.3390/ani13101619

Wang, Y., Ahsan, U., Li, H., & Hagen, M. (2022). A comprehensive review of modern object segmentation approaches. *Foundations and Trends® in*

Computer Graphics and Vision, *13*(2–3), 111–283. https://doi.org/10.1561/0600000097

Wangchuk, K., Wangdi, J., & Mindu, M. (2017). Comparison and reliability of techniques to estimate live cattle body weight. *Journal of Applied Animal Research*, *46*(1), 349–352. https://doi.org/10.1080/09712119.2017.1302876

Weber, V. A. de M., Weber, F. de L., Gomes, R. da C., Oliveira, A. da S., Menezes, G. V., Abreu, U. G. P. de, Belete, N. A. de S., & Pistori, H. (2020). Prediction of Girolando cattle weight by means of body measurements extracted from images. *Revista Brasileira de Zootecnia*, *49*. https://doi.org/10.37496/rbz4920190110

Zeiler, M. D. (2013). *Hierarchical convolutional deep learning in computer vision* [Doctoral Dissertation]. New York University.

Zhang, F., & O'Donnell, L. J. (2020). Support vector regression. Dalam *Machine Learning* (hlm. 123–140). Elsevier. https://doi.org/10.1016/B978-0-12-815739-8.00007-9

Zhang, Y., Sun, Z., Zhang, C., Yin, S., Wang, W., & Song, R. (2021). Body weight estimation of yak based on cloud edge computing. *EURASIP Journal on Wireless Communications and Networking*, *2021*(1), 6. https://doi.org/10.1186/s13638-020-01879-y

Zhu, X. (2005). *Semi-supervised learning literature survey*.

Zou, J., Han, Y., & So, S.-S. (2008). Overview of artificial neural networks. Dalam *Artificial neural networks: methods and applications* (Vol. 458, hlm. 14–22). Humana Press. https://doi.org/10.1007/978-1-60327-101-1_2