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PRECISION LIVESTOCK FARMING: CONCEPTS AND FUTURE PERSPECTIVES

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Abstract

Precision livestock farming (PLF) is increasingly being adopted as an approach that is transforming livestock farming by addressing major challenges related to food security, improving animal health, and enhancing environmental sustainability. It also offers an opportunity to attract more young people to the sector, as technology and digital solutions spark their interest and make the profession more appealing. This article reviews the basic principles, technological advances, and future implications of PLF, with a focus on cattle, pigs, and poultry. The main technologies in precision livestock farming are: multi-layered networks of wearable sensors, advanced machine vision, and acoustic monitoring systems that provide continuous real-time data to the farmer. They are integrated with sensor networks and machine learning (ML) algorithms that provide accurate information and reliable decision-making. All of this supports the transition from population-based to individualized livestock management. The data highlight significant benefits such as improved productivity, early disease diagnosis, enhanced animal welfare, and greater sustainability through optimized resource use. Many publications report a 6–9% reduction in greenhouse gas emissions and less dependence on the prophylactic use of antimicrobials. Applications illustrate its multifunctionality, from automated detection of lameness in cattle to acoustic recognition of respiratory diseases in pigs and flock-level monitoring in poultry. Despite the promising prospects, the implementation of PLF remains limited due to high capital costs, data complexity, limited connectivity in rural areas, and challenges related to data interoperability. Ethical considerations, as well as the risks of losing direct contact between humans and animals, require careful consideration.

Keywords: Artificial Intelligence, Animal Welfare, IoT, Precision Livestock Farming, Remote Monitoring, Sustainable Agriculture

INTRODUCTION

The livestock sector is undergoing a digital transformation driven by growing demands for efficiency, traceability, and sustainability (Rose et al., 2021). Precision livestock farming (PLF) is an emerging approach that uses technological tools to monitor, analyze, and manage individual animals in real time (Derkum et al., 2023). It emerged in the early 2000s and is particularly suitable for intensive animal production systems, such as cattle, pig and poultry farming (Berckmans, 2014; Black & Scott, 2002). The main goal of precision livestock farming is to increase productivity while ensuring animal welfare and environmental protection (Morrone et al., 2023). PLF has been defined as the use of advanced information and communication technologies (ICT), sensors, and algorithms to monitor and control individual animals or flocks in real time, with the aim of optimizing production, health, welfare, and environmental performance (Berckmans, 2014; Derkum et al., 2023).

In cattle systems, PLF tools such as pedometers, rumination monitors, and automated milking systems have seen increasing deployment (Precision livestock farming, n.d.; Hsu et al., 2021). In pig production, feed intake sensors, audio sensors, and imaging have been integrated in many pilot studies (Gupta et al., 2017; Mancini et al., 2021). In poultry, PLF adoption is emerging, especially in broiler houses and layer operations (Miller & Zhai, 2024; Guimaraes et al., 2024). The development of PLF systems has been closely linked to advances in sensor technology, Artificial Intelligence (AI), and the Internet of Things (IoT) (Džermeikaitė et al., 2023). The objective use of data is increasingly seen not only as a tool for economic optimization, but also as a means to enhance transparency and consumer trust (Berckmans, 2014).

MATERIALS AND METHODS

This article combines a systematic review of the literature and a summary of the main ideas according to the available scientific literature on the topic of Precision Livestock Farming. The methodology follows the structure of key publications (Berckmans, 2014; Banhazi et al., 2012), focusing primarily on reviewing the main scientific principles, technological applications, and challenges for the implementation of precision livestock farming.

The sources used are mainly scientific articles, review articles, and conference materials published in peer-reviewed journals since 1995. The review is based on the analysis of important scientific ideas, technological achievements, and difficulties in their practical application, as identified by Banhazi et al. (2012) and subsequent studies.

RESULTS AND DISCUSSION

Scientific Principles of PLF

PLF is grounded in systems engineering, data science, and ethology. Its operational framework is often aligned with the Hazard Analysis and Critical Control Points (HACCP) methodology to ensure process control in complex farm environments (Black & Scott, 2002; Banhazi et al., 2012). The main principles of PLF include identifying critical control points in livestock management, installing sensors for continuous measurement of specified parameters, analyzing data to predict future problems, and taking timely action to address them (Banhazi et al., 2012).

The main scientific principle is the idea of "the animal as a sensor" (Berckmans, 2014; Gupta et al., 2017). This means that instead of measuring only environmental parameters, PLF directly measures the animal's behavioral and physiological responses (Bochu et al., 2023). PLF is based on model-based control (Berckmans, 2014). Precision technology systems use mathematical models to predict the normal behavior and physiological state of animals. If the sensors detect something unusual, an alarm is triggered, allowing for a quick response (Berckmans, 2014; Bochu et al., 2023). This is of great importance in ensuring sustainable livestock farming systems while maintaining a balance between productivity, animal health, and environmental impact.

The latest research on the subject shows that sensor data not only informs farmers about problems, but is also used in automated animal management systems (Banhazi et al., 2012). This new understanding transforms PLF into a system that monitors and adapts to the needs of animals (Morrone et al., 2023). The role of machine learning (ML) and computer vision in behavior recognition and anomaly detection is expanding. This contributes to the development of more intelligent and autonomous livestock farming systems (Džermeikaitė et al., 2023).

Technological Applications

PLF technologies encompass a wide range of tools and systems, including automated milking machines, vision-based body weight estimation, RFID-based animal identification, and acoustic monitoring of respiratory diseases (Precision livestock farming, n.d.).

Cattle Farming

In dairy farming, wearable sensors (such as RFID tags and activity collars) track lying time, steps, and eating behavior, correlating these metrics with health status (Precision livestock farming, n.d.; Hsu et al., 2021). Robotic milking systems and inline milk sensors provide precision management and early detection of anomalies (Precision livestock farming, n.d.; Bochu et al., 2023). PLF systems can also be used for lameness detection through automated techniques (Pires et al., 2019; Lazzaretti et al., 2024). In *Precision Livestock Extensive Farming* (PLEF), GPS, GIS, and accelerometers are used to track location, feeding, and rumination (Bochu et al., 2023; Hossain et al., 2025).

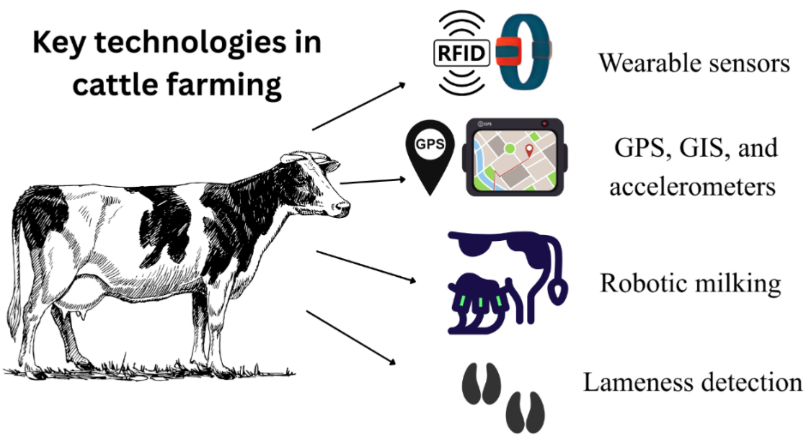

Figure 1. Key technologies applied in cattle farming.
Source: Own figure (2025).

Swine Farming

In pig farming, machine vision systems are employed to estimate weight gain and identify behavioral anomalies such as tail biting (Mancini et al., 2021; Gupta et al., 2017). Acoustic monitoring is utilized for cough recognition and early detection of respiratory diseases (Gupta et al., 2017). Water and feed intake sensors are among the most common PLF tools for swine, as changes in these parameters are key indicators of health (Gupta et al., 2017). These systems are designed to "assist farmers in taking their daily management decisions and provide early warnings" if an issue arises (Gupta et al., 2017).

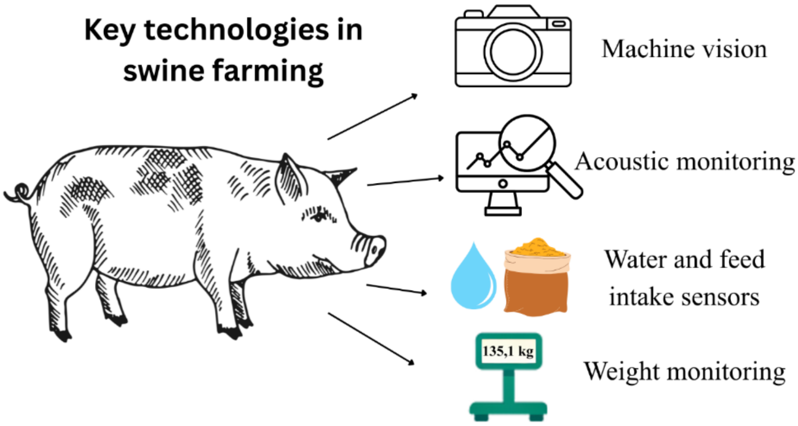

Figure 2. Key technologies applied in swine farming.
Source: Own figure (2025).

Poultry Farming

In poultry farming, where monitoring is typically conducted per-flock (Precision livestock farming, n.d.), computer vision systems track flock distribution and activity (Miller & Zhai, 2024). Sound recognition is applied to detect stress calls and monitor respiratory issues (Miller & Zhai, 2024; Guimaraes et al., 2024). Furthermore, dynamic weighing systems and image analysis are being developed to enable individual weight and welfare data collection (Guimaraes et al., 2024).

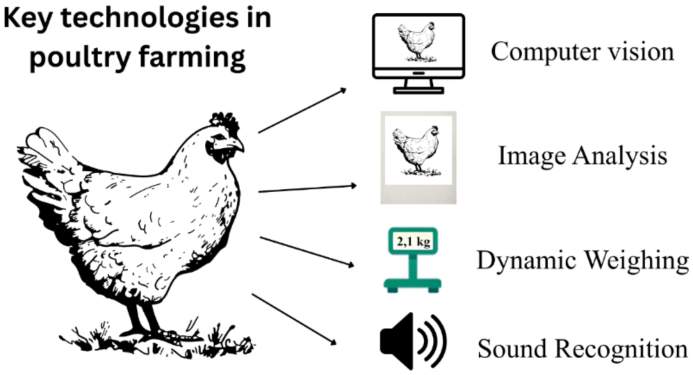

Figure 3. Key technologies applied in poultry farming.
Source: Own figure (2025).

Implementation and Limitations

The implementation of precision technologies in livestock farming remains uneven across different regions and farm types, despite technological readiness (USDA, undated). The most commonly cited limiting factors are economic. For example, high initial costs, uncertain return on investment, and difficulty in measuring long-term benefits, especially for small and medium-sized farms (USDA, undated; Vogels, 2023).

On the other hand, technical barriers include problems with data exchange and poor internet connection in rural areas, which hinders the collection and analysis of real-time data (Stelzl et al., 2024; Vogels, 2023). Cultural and social aspects also contribute to the barriers, as traditional farmers may perceive PLF as intrusive or worry that they will lose the freedom to make decisions about their animals themselves (Vogels, 2023). For the successful implementation of these technologies, a new service industry needs to be created that is responsible for hardware maintenance, data interpretation, training, and helping farmers with specific solutions to their problems (Banhazi et al., 2012; Ramirez et al., 2019; Market Research Future, 2024).

Ethical and Societal Considerations

The ethical considerations of PLF are attracting increasing attention (Häberle & Visscher, 2022). Technologies promise better outcomes for animal welfare, but they also raise concerns about the instrumentalization of animals and reduced human-animal interaction (Rose et al., 2021). Critics say that turning animals into "data points" (Bozhko et al., 2022) risks neglecting their sentient nature, reducing genuine care for them, and facilitating their further exploitation. If PLF technologies are used to "replace the farmer's eyes and ears" (Rose et al., 2021), this could lead to a loss of essential livestock management skills (Häberle & Visscher, 2022).

Another issue is data management. Questions about data ownership, consent, privacy, and usage rights remain unresolved (Li et al., 2024). There must be clear legal frameworks to ensure transparency and build trust between farmers and technology providers (Li et al., 2024; Farmonaut, n.d.-b). Techniques such as anonymization, encryption, and federated learning are crucial for data protection (Li et al., 2024).

Future Perspectives and Sustainability Integration

In addition to using advanced technologies, precision livestock farming also plays an important role in achieving global sustainability goals in the livestock sector (Sustainable Agriculture, undated). PLF fits in with these principles (Sustainable Agriculture, undated) by optimizing resource use and reducing waste (Farmonaut, undated). For example, technological management of feeding and waste can reduce greenhouse gas emissions, particularly methane from cattle (Farmonaut, undated). Various studies show that PLF can reduce the overall carbon footprint by 6–9% (Rinaldi et al., 2022).

Future developments include wider use of robots and automation for tasks such as feeding and cleaning (Farmonaut, undated-a) and advances in artificial intelligence/machine learning to improve the accuracy of predictions (Market Research Future, 2024). The introduction of 5G and edge computing is of great importance for overcoming poor internet connection in rural areas and for real-time data processing (Hossain et al., 2025).

Combining PLF with tracking systems such as blockchain can improve transparency throughout the supply chain, providing consumers with verified information on animal welfare, emissions, and product origin (Banhazi et al., 2012). This responds to the growing demand for ethical and sustainable food.

The success of PLF hinges on multidisciplinary collaboration among farmers, researchers, engineers, and policymakers (Ramirez et al., 2019; Animal Task Force, n.d.). Policymakers must provide the necessary "regulatory and financial support" (Market Research Future, 2024) to ensure equitable and inclusive technology adoption (Rinaldi et al., 2022; USDA, n.d.).

CONCLUSIONS

The application of these precision technologies in animal husbandry is still limited due to their high cost and limited evidence of their effectiveness. Other limiting factors include ethical concerns about treating animals as data rather than as living organisms. To fully exploit the potential of PLF, its development and application must be guided by economic efficiency, social acceptability, and ethical responsibility. Future efforts should prioritize technology training, which requires specific knowledge in the fields of technology and animal husbandry. Legislative measures are needed to regulate the application of technologies and transparent data management to ensure that the benefits of PLF are distributed fairly and contribute to a sustainable future for global food systems. Precision livestock farming can reduce negative environmental impacts by reducing greenhouse gas emissions and waste and lead the sector towards sustainability.

REFERENCES

Animal Task Force. (n.d.). *PLF is the management of livestock farming by continuous automated real-time monitoring/controlling of production/ reproduction, health and welfare of livestock*. Retrieved from https://animaltaskforce.eu/topics/precision-livestock-farming/

Banhazi, T. M., Lehr, H., Black, J. L., Crabtree, H., Schofield, P., Tscharke, M., et al. (2012). Precision Livestock Farming: An international review of scientific and commercial aspects. *International Journal of Agricultural and Biological Engineering, 5*(3).

Berckmans, D. (2014). Precision Livestock Farming: The solution for a sustainable livestock production. *Animal Frontiers, 7*(1), 6-11. https://doi.org/10.2527/af.2017.0102

Black, J. L., & Scott, L. (2002). *More beef from pastures: current knowledge, adoption and research opportunities*. Meat and Livestock Australia Limited: Sydney, Australia.

Bochu, C., Pirovano, L., Aletti, M., & Agostini, L. (2023). Precision Livestock Farming: Applications and Technologies for Grazing Animals. *Agriculture, 13*(2), 288. https://doi.org/10.3390/agriculture13020288

Bozhko, A., Borodin, O., Bondarenko, Y., & Obolonina, E. (2022). Ethical Concerns in Digital Livestock Farming. *AgriEngineering, 5*(1), 32. https://doi.org/10.3390/agriengineering5010032

Derkum, S., Cangar, Ö., & Banhazi, T. (2023). Precision Livestock Farming: What Does It Contain and What Can We Expect? *Animals, 13*(2), 346. https://doi.org/10.3390/ani13020346

Džermeikaitė, K., Daukšys, R., Stankevičius, K., Janeliūnas, K., Briedis, V., Katinas, L., & Šimanskas, A. (2023). Technologies and applications of precision livestock farming. *Animal Biology and Animal Husbandry, 15*(2). https://animalscipublisher.com/index.php/amb/article/html/3816/

Farmonaut. (n.d.-a). *Precision Livestock Farming: 5 Ways to Boost Productivity*. Retrieved from https://farmonaut.com/precision-farming/precision-livestock-farming-5-ways-to-boost-productivity

Farmonaut. (n.d.-b). *Safeguarding Your Farm Data: Farmonaut's Commitment to Privacy in Precision Agriculture*. Retrieved from https://farmonaut.com/precision-farming/safeguarding-your-farm-data-farmonauts-commitment-to-privacy-in-precision-agriculture

Frost, A. R., Parsons, D. J., Stacey, K. F., Robertson, A. P., Welch, S. K., Filmer, D., & Fothergill, A. (2003). Progress towards the development of an integrated management system for broiler chicken production. *Computers and Electronics in Agriculture, 39*(3), 227-240. (https://doi.org/10.1016/S0168-1699(03)00030-9)

Global Research Alliance. (2013). *Precision feeding is indicated by the Global Research Alliance (2013) as the most promising PLF technology for reducing ammonia and GHG emissions from livestock farms*. (As cited in European Commission, 2017).

Guimaraes, V., Silva, V., & Almeida, G. (2024). *Application of Precision Livestock Farming Systems to Improve Broiler Production and Welfare*. *Animals*, *14*(7), 1050. https://doi.org/10.3390/ani14071050

Gupta, S., Banhazi, T., & Vranken, E. (2017). Precision Livestock Farming: A solution for sustainable pig production. *Animal Frontiers, 7*(1), 32-38. https://doi.org/10.2527/af.2017.0107

Häberle, H., & Visscher, J. (2022). Ethical analysis of animal welfare threats related to precision livestock farming. *Frontiers in Veterinary Science, 9*, 889623. https://doi.org/10.3389/fvets.2022.889623

Hossain, Z., Khan, M. J. H., & Kim, C. K. (2025). Full article: Precision livestock farming: an overview on the application in extensive systems. *Italian Journal of Animal Science*. https://doi.org/10.1080/1828051X.2025.2480821

Hsu, J. M., Weng, H. T., Chuang, C. H., & Yang, C. Y. (2021). Wearable Internet of Things enabled precision livestock farming in smart farms: A review of technical solutions for precise perception, biocompatibility, and sustainability monitoring. *Journal of Cleaner Production, 312*(6), 127712. https://doi.org/10.1016/j.jclepro.2021.127712

Lazzaretti, A. E., Campos, D. P., & Bertotti, F. L. (2024). Lying behavior analysis in dairy calves through Precision Livestock Farming technologies. *Frontiers in Veterinary Science*. https://doi.org/10.3389/fvets.2024.1477731

Li, C., Yu, Z., & Chen, Y. (2024). *Agricultural Data Privacy: Emerging Platforms & Strategies*. University of Twente. https://research.utwente.nl/en/publications/agricultural-data-privacy-emerging-platforms-amp-strategies

Mancini, S., Schiavi, S., & Bahr, C. (2021). Precision Livestock Farming for Welfare Assessment in Pigs: A Systematic Review. *Animals, 11*(5), 1332. https://doi.org/10.3390/ani11051332

Market Research Future. (2024). *Precision Livestock Farming Market Growth, Industry Report and Trends 2034*. Retrieved from https://www.marketresearchfuture.com/reports/precision-livestock-farming-market-34172

Miller, A. R., & Zhai, J. (2024). *Precision Livestock Farming Applications in Poultry*. The University of Tennessee Extension. (https://utia.tennessee.edu/publications/wp-content/uploads/sites/269/2024/10/W1271.pdf)

Morrone, P., Drouillard, J., & Cinar, M. (2023). Precision technologies and sustainable intensification of animal agriculture. *Journal of Animal Science, 101*(10), skad206. https://doi.org/10.1093/jas/skad206

Phelan, P., McCarthy, S., & Ryan, S. (2020). Factors associated with the intensity of precision livestock farming technology adoption in pasture-based dairy systems. *Computers and Electronics in Agriculture, 172*, 105315. https://doi.org/10.1016/j.compag.2020.105315

Pires, C., Antunes, J. R., & Antunes, D. (2019). Automated lameness detection systems for cattle: A review. *Computers and Electronics in Agriculture, 161*, 19-27. https://doi.org/10.1016/j.compag.2019.03.013

Precision livestock farming. (n.d.). In *Wikipedia*. Retrieved October 4, 2025, from https://en.wikipedia.org/wiki/Precision_livestock_farming

Ramirez, A., Egenolf, K., & Banhazi, T. (2019). Key precision livestock farming (PLF) stakeholders and their interactions to drive and create applications for improving animal production systems. *ResearchGate*.

Rinaldi, M., Berckmans, D., & Manci, T. (2022). The environmental, social and economic impact of Precision Livestock Farming: A comprehensive indicator for the decision-making process. *AIR Institutional Repository*. https://air.unimi.it/handle/2434/969217

Rose, D. C., Garside, T., & Visscher, J. (2021). Integration of Ethical and Social Aspects into Precision Livestock Farming – Achieving Real-World Impact Responsibly. *Frontiers in Animal Science, 2*, 639678. https://doi.org/10.3389/fanim.2021.639678

Shao, B., & Xin, H. (2008). A real-time computer vision assessment and control of thermal comfort for group-housed pigs. *Computers and Electronics in Agriculture, 62*(1), 15-21. https://doi.org/10.1016/j.compag.2007.11.002

Stelzl, L., Zhai, J., & Schick, M. (2024). The Use of Precision Livestock Farming Technology for Improving Animal Welfare in the Context of Climate Change: Applications and Challenges. *Animals, 14*(4), 620. https://doi.org/10.3390/ani14040620

Stewart, M., Webster, J. R., Verkerk, G. A., & Schaefer, A. L. (2007). Non-invasive measurement of stress in dairy cows using infrared thermography. *Physiology & Behavior, 92*(3), 520-525. https://doi.org/10.1016/j.physbeh.2007.05.011

Sustainable Agriculture. (n.d.). *Precision Livestock Farming (PLF) and Sustainable Agriculture*. OSF. https://osf.io/ayzkp/download

USDA. (n.d.). *Adoption of Precision Agriculture*. National Institute of Food and Agriculture. Retrieved from https://www.nifa.usda.gov/grants/programs/precision-geospatial-sensor-technologies-programs/adoption-precision-agriculture

Vogels, M. (2023). Diffusion of innovation, internet access and adoption barriers for precision livestock farming among beef producers. *ResearchGate*.

Wathes, C. M., Kristensen, H. H., Aerts, J. M., & Berckmans, D. (2008). Is precision livestock farming an engineer's daydream or nightmare, an animal's friend or foe, and a farmer's panacea or pitfall? *Computers and Electronics in Agriculture, 64*(1), 2-10. https://doi.org/10.1016/j.compag.2008.05.006

Zion, B., Alchanatis, V., Ostrovsky, V., Barki, A., & Karplus, L. (2007). Real-time underwater sorting of edible fish species. *Computers and Electronics in Agriculture, 56*(1), 34-45. https://doi.org/10.1016/j.compag.2006.12.001

Wang, Y., Yang, W., Winter, P., & Walker, L. (2008). Walk-through weighing of pigs using machine vision and an artificial neural network. *Biosystems Engineering, 100*(1), 117-125. https://doi.org/10.1016/j.biosystemseng.2007.12.010

Frost, A. R. (2000). The development and evaluation of image analysis procedures for guiding a livestock monitoring sensor placement robot. *Computers and Electronics in Agriculture, 28*(3), 229-242. (https://doi.org/10.1016/S0168-1699(00)00140-5)

Mottram, T. T. (1997). Automatic monitoring of the health and metabolic status of dairy cows. *Livestock Production Science, 48*(3), 209-217. (https://doi.org/10.1016/S0301-6226(97)00008-X)

Brandl, N., & Jorgensen, E. (1996). Determination of live weight of pigs from dimensions measured using image analysis. *Computers and Electronics in Agriculture, 15*(1), 57-72. https://doi.org/10.1016/0168-1699(96)01015-8

Park, B., Chen, Y. R., & Nguyen, M. (1998). Multi-spectral Image Analysis using Neural Network Algorithm for Inspection of Poultry Carcasses. *Journal of Agricultural Engineering Research, 69*(4), 351-363. https://doi.org/10.1006/jaer.1997.0253

Cronin, G. M., Borg, S. S., & Dunn, M. T. (2008). Using video image analysis to count hens in cages and reduce egg breakage on collection belts. *Australian Journal of Experimental Agriculture, 48*(5), 768-772. https://doi.org/10.1071/EA07340

Chedad, A., Moshou, D., Aerts, J. M., Hirtum, A. V., Ramon, H., & Berckmans, D. (2001). Recognition system for pig cough based on probabilistic neural networks. *Journal of Agricultural Engineering Research, 79*(4), 449-457. https://doi.org/10.1006/jaer.2001.0709

Wouters, P., Geers, R., Parduyns, G., Goossens, K., Truyen, B., & Goedseels, V. (1990). Image-analysis parameters as inputs for automatic environmental

temperature control in piglet houses. *Computers and Electronics in Agriculture, 5*(3), 233-246. https://doi.org/10.1016/0168-1699(90)90013-I
Moshou, D., Chedad, A., Hirtum, A. V., De Baerdemaeker, J., Berckmans, D., & Ramon, H. (2001). Neural recognition system for swine cough. *Mathematics and Computers in Simulation, 56*(4-5), 475-487. (https://doi.org/10.1016/S0378-4754(01)00344-9)
Maltz, E., Livshin, N., Antler, A., Edan, Y., Matza, S., & Antman, A. (2003). Variable milking frequency in large dairies: performance and economic analysis models and experiments. In *1st European Precision Livestock Farming Conference*. Berlin, Germany: Wageningen Academic Publisher.
Niemi, J. K., Sevón-Aimonen, M., Pietola, K., & Stalder, K. J. (2010). The value of precision feeding technologies for grow-finish swine. *Livestock Science, 129*, 13-23. https://doi.org/10.1016/j.livsci.2009.11.006