Robotics For Animal Behavior and Welfare

Keregallikoppalu Hemanth Gowda, Rachaiah Guruprasad, Vankayala Jagadeeswary

The integration of robotics into animal behaviour analysis and welfare is transforming the way animals are monitored, studied, and cared for across sectors such as agriculture, laboratory research, and wildlife conservation. This chapter explores the rising significance of robotics especially when combined with Artificial Intelligence (AI) and the Internet of Things (IoT) in enhancing animal welfare through non-invasive, automated, and adaptive systems. Key applications include robotic milking and feeding systems, biomimetic robots in behavioural studies, drone-based wildlife tracking, and AI-driven behaviour monitoring. These technologies improve efficiency, standardize experimental protocols, and reduce human-induced stress in animals. The chapter also examines emerging innovations such as therapeutic robots, conservation bots, and AI systems capable of interpreting animal emotions and social behaviours. While robotics offers vast potential, it also presents challenges including biological variability, ethical considerations, and the need for cross-disciplinary collaboration. Emphasizing the importance of animal-centric design, the chapter calls for ethical frameworks like the Five Freedoms and the Three Rs to guide responsible deployment. The future of animal welfare lies in the collaborative evolution of robotics, science, and compassion.

Keywords: *Animal Welfare, Artificial Intelligence, Behavioural monitoring, Internet of things, Precision livestock farming, Robotics*

Keregallikoppalu Hemanth Gowda[1*], Rachaiah Guruprasad[2], Vankayala Jagadeeswary[3]
[1]Department of Veterinary Physiology & Biochemistry, Veterinary College, KVAFSU, Hassan, Karnataka, India.
[2]Department of Livestock Production Management, Veterinary College, KVAFSU, Hassan, Karnataka, India.
[3]Department of Veterinary & A.H. Extension Education, Veterinary College, KVAFSU, Bengaluru, Karnataka, India.

[*]Email: hemannagowda@kvafsu.edu.in

Publisher: Cornous Publications LLP, Puducherry, India.
AI and Robotics in Animal Science
Editor: Dr. Sanjib Borah, Dr. Simson Sore
ISBN: 978-81-993853-6-8
DOI: https://doi.org/10.37446/edibook202024/37-46

Introduction

Animal welfare has become a critical, ethical, economic and scientific priority. With global demand for meat, dairy and eggs projected to increase by over 70% by 2050, the livestock sector faces immense pressure to balance efficiency with humane practices. Concurrently, research involving companion animals, laboratory testing and wildlife conservation necessitates high-fidelity behavioural analysis without intrusive methods. Robotics, particularly when integrated with Artificial Intelligence (AI) and the Internet of Things (IoT), is driving a profound transformation in how animals are monitored, studied and cared for.

Traditional methods of animal behaviour analysis, such as direct observation, video recordings, and sensor-based tracking systems, often face challenges related to scalability, objectivity, and consistency. Robotics, particularly when integrated with AI and the IoT, presents a transformative alternative, enabling automated, precise and non-invasive monitoring and interaction with animals across various contexts, including laboratory research, agriculture and conservation (Krause et al., 2011). The convergence of robotics and animal sciences has opened new avenues for understanding, analyzing and enhancing animal welfare. By incorporating robotic systems into behavioural studies, researchers can collect high-resolution data, minimize human-induced bias and develop welfare-improving technologies. This chapter delves into current advancements, case studies, ethical considerations and future directions for robotics in animal behaviour analysis and welfare.

The application of robotics in animal behaviour research has expanded significantly in recent years due to advancements in robotic technology and decreasing costs. Robots are now employed in two primary ways within behavioural studies. Firstly, robots are utilized in playback experiments across various invertebrate and vertebrate species to simulate behaviors in a controlled manner, allowing researchers to observe and analyze the responses of focal animals. Secondly, robotics serves as a modelling tool to investigate the mechanisms underlying behaviors. In this approach, known as biomimetic robotics, researchers program robots with different algorithms and compare their behaviors to those of focal animals, providing insights into the functional aspects of animal behaviour (Patricelli, 2011). This dual application of robotics enhances the precision and scope of behavioural studies, offering new avenues for understanding complex animal behaviours.

What Are Robots?

Robots are machines engineered to perform actions that emulate those of humans or non-human animals. Typically, they are electromechanical systems designed to convey a sense of agency through their appearance or movements. These movements can be controlled by experimenters or programmed to interact with the environment independently. The degree of similarity between the robot's movements and appearance and the model organism varies. Some robots are designed to closely mimic the model animal, as is commonly the case in robot playback experiments. In these experiments, robots are used to simulate behaviors in a controlled manner to study the responses of focal animals. Other robots may bear little resemblance to the model organism but are designed to mimic specific behavioural mechanisms of interest to the researcher. This approach, known as biomimetic robotics, involves programming robots with different algorithms and comparing their behaviors to those of focal animals to gain insights into the underlying mechanisms of behaviour (Patricelli, 2011). As technology advances, the distinction between robots used for playback experiments and those used for modelling behavioural mechanisms is becoming less pronounced, with autonomous robots being tested in interactions with live animals.

What Is Animal Behaviour Robotics?

Robotics in animal behaviour analysis refers to the use of mechanical systems often mobile, sensor-equipped and AI-guided to monitor, simulate, or interact with animals. These technologies enable minimally invasive, real-time monitoring and promote animal welfare by reducing stress, pain and behavioural anomalies. These systems span:

- **Precision Livestock Farming (PLF)**: Robotic milkers, feeders and monitors.

- **Ethorobotics**: Biomimetic robots used in ethological studies (e.g., faux frogs, robo-fish).
- **Wildlife Drones and IoT Feeders**: Autonomous units used to track and interact with animals in the wild.
- **Therapeutic or Assistive Devices**: For pets and laboratory animals

Why Now? Drivers of Adoption

1. **Labor shortages**: A chronic decline in rural livestock workers makes automation necessary.
2. **Regulations**: The country specific and OIE standards require stricter welfare protocols.
3. **Technological maturity**: Costs of sensors, AI chips and small-scale robotics have fallen sharply.
4. **Research refinement**: Robots offer standardization in animal experiments, reducing the number of live animals needed (Liang et al., 2022).

Applications of Robotics for Animal Behaviour and Welfare

1. **Automated Monitoring Systems**
   Automated monitoring systems using robotics have become increasingly effective in observing animal behaviour across diverse environments. Mobile ground robots and aerial drones, such as unmanned aerial vehicles (UAVs), are now widely deployed for real-time monitoring of livestock and wildlife. These systems can track migratory patterns, detect signs of distress and count animal populations with minimal disturbance (Christie et al., 2016). In laboratory and agricultural settings, robotic platforms integrated with computer vision and machine learning are used to monitor behavioural patterns in rodents, poultry and pigs enabling the detection of social interactions, stereotypic behaviors and locomotor anomalies (Mathis et al., 2018).

   Drone Swarms for Wildlife & Livestock – Innovations like drone swarms developed by Hungarian researchers demonstrate the potential of bio-inspired robotics; these swarms of over 100 autonomous drones, modelled on pigeon flocks and horse herds, coordinate collision-free in real-time and can scale up to 5,000 units for expansive and non-invasive wildlife and livestock monitoring (Jonas Peter et al., 2025).

   IoT Smart Feeding Hubs -In Zoo Zurich's rainforest enclosure, an RFID-enabled feeding station for mouse lemurs logged weight and visit duration over LoRaWAN with >98% precision paving the way for passive, non-invasive behavioural tracking (Jonas Peter et al., 2025).

   Rodent Neuroscience via Zoo inspired Robots -Proposes robotic replicas (robotic animals) for standardized mouse behavioural testing offering precise, replicable social and locomotor stimuli (d'Isa, 2025).

2. **Robotic Animal Models (Bio Hybrid / Ethorobotics)**
   Biomimetic robots, such as Robofish and RoboRoach, are increasingly utilized to study animal social behaviour by integrating into groups and eliciting natural responses. These robots serve as standardized social stimuli, overcoming the variability inherent in live conspecifics. For instance, Robofish, designed to mimic the appearance and movement of guppies, has been shown to be accepted by live fish and can be programmed to interact in specific ways, allowing researchers to study social responsiveness and leadership within groups. Similarly, RoboRoach involves attaching

a small device to a cockroach, enabling researchers to control its movements and study its behaviour in response to various stimuli. These robotic models provide valuable insights into the mechanisms underlying social interactions and collective behaviour in animals. (Krause et al., 2011; Romano et al., 2017).

3. **Interactive Environments**
   Intelligent robotic systems have been implemented in enrichment strategies. Robotic balls or drones can engage zoo or captive animals in physical and cognitive exercises. In dairy farms, autonomous robotic brushes and feeders adapt to animal needs, promoting natural behaviors and reducing stress (Berckmans, 2017).

   IoT-Enabled Monitoring: Autonomous drones and sensor-equipped feeders collect long-term behavioural data in conservation zones.

   Anti-Poaching Bots: Bots with thermal sensors detect illegal activity and alert rangers in real time. Drones have successfully deterred poachers in Kenyan reserves.

4. **Enhancing Animal Welfare Through Robotics:** The use of robots oriented at animal welfare includes;

   Precision Livestock Farming (PLF): Robotic systems such as automated milking machines, feeders and manure scrapers are integral to PLF. These technologies enable continuous monitoring of health indicators like temperature, gait and rumination, facilitating early illness detection and enhancing both productivity and animal welfare (Wathes et al., 2008).

   Stress Reduction and Comfort: Mobile robots are employed to gently herd cattle using predictable, non-threatening movements, thereby reducing stress and injury risks compared to human handling (Lee et al., 2021).

   Veterinary Robotics: Robotic systems equipped with diagnostic tools perform non-invasive health assessments. For wildlife, drone-based evaluations utilizing thermal imaging and AI provide real-time diagnostics without the need for capture or sedation (Seymour et al., 2017) In laboratory settings, zoo inspired robots are used to study neurological and behavioural responses in rodents with high precision (d'Isa, 2025). Surgical assist robots and smart diagnostic tools further reduce invasiveness and improve accuracy in animal healthcare.

   Therapeutic and Monitoring Devices: Wearable devices, robotic pet brushes and autonomous play bots for dogs and cats contribute to animal welfare by offering enrichment and stress reduction.
   Collectively, these robotic innovations are transforming animal care by enhancing monitoring capabilities, reducing human-induced stress and improving overall welfare standards.

5. **Computer Vision and AI in Behaviour Monitoring - Real-time Behaviour**

   Classification: Computer vision models trained on thousands of hours of video can now:
   - Detect abnormal gait (lameness in cattle)
   - Recognize signs of heat or illness

- Track social hierarchy and aggression

6. Robots in Laboratory Behavioural Studies

- **Ethorobotics and Faux-Animal Robots:** Ethorobotics uses robotic replicas (e.g., robotic lizards, frogs) to test responses from live animals. These robots standardize stimuli and reduce ethical concerns.

- **Maze Navigation and Cognitive Tasks:** Robots assist in rodent cognitive tasks using automated maze systems, allowing for reduced handling and real-time behaviour tracking.

Case Studies

1. **Robofish and Shoaling Behavior:** Researchers at the University of Graz used a robotic fish to integrate into shoals of zebrafish, studying leadership and collective movement dynamics. The robot could influence group behavior, offering insights into social cognition and leadership in fish (Butail et al., 2013).

2. **Poultry Monitoring Systems:** In commercial poultry operations, vision-based robotic systems have been used to detect changes in walking patterns that predict lameness. This allows for early intervention and reduces suffering, showing a direct link between robotics and welfare improvement (Van Hertem et al., 2017).

3. **Swarm Intelligence & Collective Behavior:** Drone algorithms modelled after animal flocks illustrate decentralized coordination potentially transferable to herding, environmental surveying and structure maintenance (apnews.com, 2024).

4. **Zebrafish Embryo Robot Sorting:** Micro-robotic systems integrated with YOLOv5 vision algorithms sorted zebrafish embryos autonomously showing early promise for high-throughput developmental and welfare studies (Diouf et al., 2024)

Building Animal-Centric Robotics

To meaningfully contribute to animal welfare, robotics must be developed in close collaboration with:

A. **Ethologists and Animal Behaviorists -** Animal scientists provide critical insight into species-specific behaviors, stress signals and social dynamics. For example, understanding tail posture in dogs or pecking order in poultry enables robotic systems to make context-aware decisions and avoid causing anxiety or disruption (Würbel, 2017).

B. **Veterinarians and Welfare Scientists -** Veterinarians help identify early biomarkers of disease or discomfort. Robotic systems, guided by clinical thresholds, can serve as early warning tools. For example, robotic monitors might detect changes in rumination in cattle or altered gait in horses; both early indicators of potential health issues (Tuyttens et al., 2022).

C. **Engineers and Roboticists -** Collaborative design requires balancing technological feasibility with biological authenticity. Engineering a robot that mimics the movement of a fish or responds to a dog's bark involves fluid dynamics, machine learning, and actuation technology all tailored to suit the animal's perceptual system (Crespi et al., 2013).

D. **Artificial Intelligence Specialists -** AI plays a central role in transforming raw sensor data into meaningful behaviour analytics. New advances in deep learning allow for real-time pose estimation, emotion detection, and predictive modelling of behaviour patterns (Graving et al., 2019). For instance, AI can now detect lameness in cow's days before it becomes visually obvious.

Challenges and Limitations in use of robots

1. **Biological Variability -** Animals are individuals. What works for one might not work for another. Robotic systems must be adaptive, capable of learning and responding to different temperaments, health conditions and developmental stages (Miller et al., 2020).

2. **Sensor Intrusiveness -** While miniaturization is progressing, some devices (e.g., GPS collars, implantable sensors) still risk altering animal behavior. The trade-off between data accuracy and animal comfort must be carefully evaluated in each context.

3. **Ethical and Regulatory Barriers -**The use of robots in animal environments raises regulatory questions, particularly in farming, research and wildlife conservation. There are few global standards yet governing the design, deployment, or data handling of these systems (Sandøe et al., 2019).

4. **Data Privacy and AI Bias -** AI models trained on limited datasets may embed biases, leading to misinterpretations of behaviors, especially across diverse breeds or species. Ongoing data validation, transparent algorithms and explainable AI are critical to ensure ethical use (Jacobs & Bradley, 2023).

5. **Ethical Considerations in use of robots -** Animal Perception of Robots; Understanding how animals perceive robots is crucial to ensure interventions do not cause unintended stress or behavioural disruptions. Studies indicate varying responses across species some perceive robots as neutral, while others show signs of fear or avoidance (Bierbach et al., 2018). Data Privacy and Human Oversight; Increased automation may reduce the presence of skilled caretakers, which could have long-term implications for animal well-being. Ethical robotics in animal welfare should always incorporate human oversight, transparency and context aware decision-making systems (Sandini & Vernon, 2018). Trust, Oversight & Data Ethics; Human monitoring remains critical even with high-tech behavioural instruments (e.g. RFID/AI systems); human oversight ensures welfare-protective protocols and avoids reliance on potentially biased algorithms.

Use of Robotic Systems in Livestock Farming

The livestock sector is undergoing significant transformations driven by technological advancements, particularly through the integration of robotic systems. These innovations are enhancing operational efficiency, reducing labor costs and improving animal welfare.

Robotic Milking Systems: Automated milking machines allow cows to be milked at their convenience, reducing stress and increasing milk yield. These systems use sensors to identify individual cows and monitor milk quality, providing valuable data for herd management. For instance, a dairy farm reported a 28.5%

increase in milk production after adopting robotic milking systems, rising from 7,000 to 9,000 liters per cow annually

Automated Feeding Systems: Robotic feeders ensure that each animal receives a diet tailored to its specific needs, optimizing nutrition and enhancing growth and productivity. These systems monitor factors such as milk yield and body weight to dispense the appropriate amount of feed.

Health Monitoring and Veterinary Robotics: Wearable devices and robotic systems equipped with sensors track vital signs, activity levels and behaviour patterns of livestock. This real-time monitoring enables farmers to detect early signs of illness or distress, allowing for timely interventions and improved herd health (Dilaver & Dilaver, 2024)

Animal Welfare Enhancements: Robotic cleaning systems maintain hygiene standards in animal shelters, reducing the risk of disease and providing a comfortable environment for livestock. Additionally, automated herd management systems monitor animal movements and optimize social interactions within herds, further enhancing animal well-being. The adoption of robotic systems in livestock farming offers numerous benefits, including increased efficiency, reduced labor costs and improved animal welfare. As technology continues to advance, it is expected that these systems will become more widely used, leading to a more sustainable and innovative industry.

Future Outlook

Looking ahead, robotics in animal behaviour and welfare is poised for transformative developments;

- **Cross-Species Communication Interfaces**

  Experimental systems are underway to decode and respond to animal vocalizations. For example, AI models can now distinguish between pig grunts signalling stress or pleasure, with over 90% accuracy. Future robotic systems may be able to "speak back" using movement, light, or sound patterns calibrated to species-specific communication.

- **Robotic Therapists for Behavioural Enrichment**

  In settings such as sanctuaries or labs, zoomorphic robots may provide consistent companionship or stimulation for socially isolated animals. These systems could become a form of therapy especially for animals that have experienced trauma.

- **Conservation Robotics**

  Low-cost robotic kits for citizen scientists could extend animal welfare monitoring to remote or underserved areas, enabling distributed data collection on endangered species, strays, or livestock conditions fueling open datasets and collaborative analysis.

- **Educational Tools for Empathy and Awareness**

  Robotic animal replicas integrated into schools and museums may not only simulate realistic animal behavior, but also serve to educate children and the public about animal emotions, cognition and ethical treatment.

- **Advances in AI, soft robotics, and sensor miniaturization** promise a new era of precision and compassion in animal welfare. Potential developments include; **Bio-hybrid robots** that interact at a physiological level, **Swarm robotics** for wildlife monitoring, **social robotics** that adapt to individual animal personalities, **Ethological AI** capable of learning species-specific behavior.

Conclusion

As robotics becomes increasingly integrated into the study and enhancement of animal behaviour and welfare, it is crucial to ensure that these technologies are designed and implemented with a focus on the well-being and autonomy of animals. Robotic systems should be developed to align with ethical frameworks that prioritize animal-centric values, ensuring that interventions do not disrupt natural behaviors or diminish the quality of life for animals. For instance, using drones to monitor elephant migration, employing robotic toys to encourage play in shelter dogs, or simulating shoal mates for zebrafish can provide valuable insights and support for animals without compromising their natural behaviors.

To achieve this, it is essential to establish and adhere to ethical guidelines that govern the development and deployment of robotic technologies in animal care. These guidelines should encompass principles such as the Five Freedoms, which include freedom from hunger and thirst, discomfort, pain, injury or disease, freedom to express normal behaviour and freedom from fear and distress. Additionally, the Three Rs; Replacement, Reduction and Refinement should be applied to minimize the use of animals in research and ensure that any necessary use is conducted with the highest standards of welfare. Furthermore, adopting frameworks like the Five Domains model, which assesses animal welfare through nutrition, environment, health, behaviour and mental state, can provide a comprehensive approach to evaluating the impact of robotic interventions on animal well-being. By integrating these ethical considerations into the design and application of robotics in animal care, we can ensure that technology serves as a guardian of animal welfare, enhancing their lives without compromising their natural behaviors or autonomy.

Conflict of Interest Statement: NIL

References

Associated Press. (2024, May 14). *Animal-inspired swarms of drones could be a game-changer for defense*. AP News. https://apnews.com/article/autonomous-drones-animal-swarms 0e146f4221e81f4442674a125f86501d

Berckmans, D. (2017). General introduction to precision livestock farming. *Animal Frontiers, 7*(1), 6–11.

Bierbach, D., Landgraf, T., Romanczuk, P., Lukas, J., Nguyen, H., Wolf, M., & Krause, J. (2018). Insights into the social behaviour of fish: A robotic platform to study animal–robot interactions. *Ethology, 124*(6), 389–398. https://doi.org/10.1111/eth.12741

Butail, S., Polverino, G., Phamduy, P., Del Sette, F., & Porfiri, M. (2013). Influence of robotic shoal size, configuration, and activity on zebrafish behaviour in a free-swimming environment. *Behavioural Brain Research, 250*, 78–86. https://doi.org/10.1016/j.bbr.2013.04.005

Christie, K. S., Gilbert, S. L., Brown, C. L., Hatfield, M., & Hanson, L. (2016). Unmanned aircraft systems in wildlife research: Current and future applications of a transformative technology. *Frontiers in Ecology and the Environment*, *14*(5), 241–251.

Crespi, A., Karakasiliotis, K., Guignard, A., & Ijspeert, A. J. (2013). Swimming and crawling with an amphibious snake robot. *IEEE Transactions on Robotics*, *29*(3), 710–720. https://doi.org/10.1109/TRO.2013.2240170

d'Isa, R. (2025). Robotic animals as new tools in rodent neuroscience research: Proposed applications of zooinspired robots for mouse behavioural testing. *Frontiers in Behavioural Neuroscience, 19,* 1545352. https://doi.org/10.3389/fnbeh.2025.1545352

Dilaver, H., & Dilaver, K. F. (2024). Robotics systems and artificial intelligence applications in livestock farming. *Journal of Animal Science and Economics, 3*(2), 63–72.

Graving, J. M., Chae, D., Naik, H., Li, L., Koger, B., Costelloe, B. R., & Couzin, I. D. (2019). DeepPoseKit: A software toolkit for fast and robust animal pose estimation using deep learning. *Nature Methods, 16,* 605–608. https://doi.org/10.1038/s41592-019-0502-x

Jacobs, B., & Bradley, M. (2023). Transparent AI in animal welfare: Challenges and best practices. *AI & Ethics, 4*(2), 89–105.

Jonas, P., Luder, V., Davis, L. R., Schulthess, L., & Magno, M. (2025). Smart feeding station: Non-invasive, automated IoT monitoring of Goodman's mouse lemurs in a semi-natural rainforest habitat. In *Proceedings of the IEEE International Instrumentation and Measurement Technology Conference*. https://doi.org/10.48550/arXiv.2503.09238

Krause, J., Winfield, A. F. T., & Deneubourg, J. L. (2011). Robotic fish in animal behavioural research: A review. *Ethology, 117*(8), 679–685. https://doi.org/10.1111/j.1439-0310.2011.01915.x

Lee, S. Y., Kim, Y., Kim, H. T., & Lee, H. (2021). Development of a mobile robot to support cattle movement and monitor behavior. *Biosystems Engineering, 207,* 20–32. https://doi.org/10.1016/j.biosystemseng.2021.04.011

Li, L., Ravi, S., & Wang, C. (2022). Editorial: Robotics to understand animal behaviour. *Frontiers in Robotics and AI, 9,* 963416. https://doi.org/10.3389/frobt.2022.963416

Mannioui, A., Zizioli, D., Fassi, I., Boudaoud, M., Legnani, G., & Haliyo, S. (2024). Robotic sorting of zebrafish embryos. *Journal of Micro-Bio Robotics, 20*(3), Article 3. https://doi.org/10.1007/s12213-024-00167-y

Mathis, A., Mamidanna, P., Cury, K. M., Abe, T., Murthy, V. N., Mathis, M. W., & Bethge, M. (2018). DeepLabCut: Markerless pose estimation of user-defined body parts with deep learning. *Nature Neuroscience, 21*(9), 1281–1289. https://doi.org/10.1038/s41593-018-0209-y

Miller, L. J., Vicino, G. A., Sheftel, J., & Lauderdale, L. K. (2020). Animal individuality and behavior: Translating variability into welfare insight. *Animal Behaviour, 166,* 99–109. https://doi.org/10.1016/j.anbehav.2020.05.019

Patricelli, G. L. (2010). Robotics in the study of animal behavior. In M. D. Breed & J. Moore (Eds.), *Encyclopedia of Animal Behaviour* (Vol. 3, pp. 91–99). Academic Press. http://www.elsevier.com/locate/permissionusematerial

Romano, D., Donati, E., Benelli, G., & Stefanini, C. (2017). A review on animal–robot interaction: From bio-hybrid organisms to mixed societies. *Biological Cybernetics, 111*(3), 177–195.

Sandini, G., & Vernon, D. (2018). The human and the robot in the loop. *Nature Machine Intelligence, 1*(1), 6–7.

Sandøe, P., Gjerris, M., & Christiansen, S. B. (2019). Ethics of animal use in science: Balancing interests and minimizing harm. *Veterinary Record, 184*(3), 95–100. https://doi.org/10.1136/vr.104571

Seymour, A. C., Dale, J., Hammill, M., Halpin, P. N., & Johnston, D. W. (2017). Automated detection and enumeration of marine wildlife using unmanned aircraft systems (UAS) and thermal imagery. *Scientific Reports, 7*(1), 45127.

Tuyttens, F. A. M., Ampe, B., Ruelokke, M., Song, X., & Viazzi, S. (2022). Precision livestock farming: The importance of a multidisciplinary approach. *Animal, 16*(1), 100386. https://doi.org/10.1016/j.animal.2021.100386

Van Hertem, T., Norton, T., Berckmans, D., & Vranken, E. (2017). Early warning systems for tail biting in pigs: Current status and future perspectives. *Agricultural Systems, 160*, 66–75. https://doi.org/10.1016/j.agsy.2017.01.004

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.