Herding livestock – the phoenix rises from the ashes? Digital herding as a future tool for grazing livestock

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Abstract
Today, sustainable management of grazing livestock requires high efforts in management and fencing. Nowadays, several developments in digital technologies for herding grazing animals are arising.
We conducted a systematic review on current developments in digital technologies for managing grazing animals within the landscape. We mainly focused on cattle (*Bos taurus*) and sheep (*Ovis aries*). We highlight the most promising developments of virtual fencing used in recent research to evaluate effectiveness, animal behaviour and welfare. Moreover, we highlight current research in digital herding by drones and robots. We discuss the potential and current limitations of digital tools for sustainable grazing management.
Recent study results showed that virtual fences are highly efficient in keeping cattle within allocated pasture areas. So far, there has been no evidence for harmful impacts on animal welfare or reduction in animal performance. First findings suggest that drones can also herd and move animals. However, knowledge on the efficiency and potential effects on animal welfare when using drones is limited. First findings have shown that robots are able to gather animals to a specific location and heart-rate and blood tests showed that the animals were less stressed by the robot than they were by a human. However, research on herding drones and robots is still in its infancy.
Digital tools provide the opportunity for precise livestock movement control and could facilitate the implementation of both productive and biodiversity-friendly grazing.

Introduction
In agricultural practice, the proper use of pasture by grazing animals requires time-consuming and cost-intensive management and fencing. For example, for efficient fresh fodder allocation dairy systems rely on temporary shifts of the fences and available paddocks, whereby conventional fencing is a rigid system and for certain locations e.g., restoration areas or nature conservation tasks are very difficult to use.
Nowadays, several developments in digital technologies are promising for managing grazing animals (e.g., French *et al.* 2018). Digital herding such as virtual fencing is a promising, innovative technology that allows flexible, sustainable, and efficient grazing management by a fine-tuned control of cows' spatiotemporal grazing behavior and precise adjustment of small-scale grazing pressure. Novel digital tools could facilitate the implementation of both productive and biodiversity-friendly grazing management approaches and supersede classical grazing categories by highly flexible and need-based management options. Previous review papers (Umstatter 2011, Anderson et al. 2014) gave important insights into the first developments of virtual fencing. In our primilary systematic review, we go beyond this and address first tests of the most promising virtual fencing technologies for managing and controlling grazing animals within the landscape. Moreover, we discuss the potential of herding drones and robots for targeted control of livestock movement.

Methods
We searched the literature for digital herding technologies such as virtual fences, drones and robots. Our literature research mainly focused on cattle (*Bos taurus*) and domestic sheep (*Ovis aries*), but most of the information is applicable to other livestock species as well. Articles in English were chosen using the 'Web of Science' section of the data base ISI Web of Knowledge (**http://pcs.isiknowledge.com**) and Scopus for all available publication years. The search for digital herding technologies was based on the following search criteria: Topic= (*virtual OR wireless OR fenceless OR stakeless OR automated OR digital OR drone OR robotic* fencing Or herding) AND (dairy cows OR cattle OR sheep OR ruminants) AND (animal control OR movement control OR animal management OR animal monitoring) AND (response OR behaviour) AND (pasture OR grazing *management) AND (animal welfare OR ethically acceptable) AND (nature OR*

*environmental * conservation OR landscape OR habitat * restauration) AND (grazing OR pasture * efficiency OR utilization) AND (agronomic outcome OR performance).*

Results and Discussion

Digital herding – flexible tools to any grazing regime

Stocking method such as rotational or strip grazing is not itself an advanced management strategy guarantying well-balanced pasture utilization. It's a complex interplay of controlling the spatio-temporal dynamics of foraging as the stocking rate, paddock size, time of forage allowance and the individual animal's direction and speed that determine the defoliation frequency of individual plants. Conventionally fenced paddocks are rather static and cannot provide such a high level of flexibility and precision in spatial and temporal stocking management and dynamic foraging as it is supposed for digital herding tools (see Anderson et al. 2014).

While robotics have experienced a rapid development and popularity for crop farming to improve crop production yields (Birrell et al. 2020), the research and development of digital animal herding is still in its infancy and mainly limited to virtual fencing.

Virtual fencing

Virtual fencing combines positioning techniques (e.g., GPS) with a conditioned pre-warning stimulus and an aversive stimulus to prevent animals from crossing a virtually defined border. There is no physical visible barrier anymore. If an animal does not respond to the pre-warning stimulus, an aversive stimulus is given in the form of an electric pulse (e.g., Umstatter 2011). Globally, four sophisticated virtual fencing systems have been developed and are about to enter the market. These systems consist of a collar that transmits positional data via GPS and devices that enable farmers to flexibly establish pasture boundary lines remotely by shifting length and latitude coordinates using Apps on a smartphone, tablet or PC from a home office or even on the road. All these systems allow monitoring of livestock 24/7 at least for their location and delivered stimuli. The spatial centre of technological invention and extensive research of virtual fencing is in Australia. From Asia, Africa and South America we found no studies. Whereas in Australia extensive research on virtual fencing has been published since the late 2000s, studies from Europe and the USA appeared more slowly. So far, cattle, sheep, and goats have been tested using different virtual fencing systems, whereby cattle was the most intensively tested species (see Table 1). For cattle, most studied breeds were Angus, which is principally reared for beef and well adapted to extensive grazing, followed by the high-producing dairy breed Holstein, and the robust dairy breed Jersey with highest metabolic rate and highest herd performance in milk output. Mostly, heifers were used within virtual fencing trials, followed by non-lactating and lactating cows. Only few studies tested virtual fencing on steers and no currently published study used calves in trials. Testing a wide range of different grazing animal breeds and growth stages is highly important to determine the learnability, effectiveness and safety of virtual fencing technology in herding animals and its impacts on animal welfare as physiological, psychological, and social factors can widely differ.

Recent studies indicated that cattle and sheep successfully learn to associate the pre-warning sound announcing the electrical pulse when moving towards the virtual fence line. Furthermore, the number of received electrical pulses distinctly decreases within a few days of training, and escapes from the virtual fence border into the exclusion zone are less than 3% (e.g., Campbell et al. 2019, Hamidi et al. 2022, Aaser et al. 2022, Boyd et al. 2022). With increasing time on virtual fenced grazing areas interactions with the electrical pulse rarely occur, even if grazing area is regularly shifted (e.g., Asser et al. 2022, Boyd et al. 2022). For indicating welfare standards of virtual fencing systems, stress measures such as behavioral response and patterns (time budgets) in lying, grazing, rumination, resting, and travelled distance and herbage intake have been recently investigated. Moreover, increased fecal cortisol metabolite (FCM) concentrations can also indicate discomfort in cattle. First studies found no evident differences in fecal (e.g., Campbell et al., 2019, Hamidi et al. 2022, Sonne et al. 2022) and milk cortisol metabolites (Verdon et al. 2021) between virtual and conventional electrical fencing. Furthermore, differences in behavioral time budgets were minor between conventional electrical and virtual fencing (Campbell et al. 2019) or when moving virtual borders (e.g., Verdon et al. 2021) or were not present at all (Marini et al. 2022, Hamidi et al. 2022). Moreover, current research uses GPS locations of individual animals to assess if the spatial distribution of animals among the grazing area and their time spent on certain areas within the pasture is affected by the presence of the virtual fence. So far, no evidence has been reported that there is avoidance of pasture areas near the virtual fence line (e.g., Aaser et al. 2022, Lomax et al. 2019).

Virtual fencing has an incredible potential for shifting grazing management to more flexible, controllable, precise, sustainable, and less labour-intensive standards. However, the agronomic and ecological benefits of

VF still need to be assessed under different socio-economic and ecological conditions of dairy and beef cattle farms across different grazing systems (Horn and Isselstein 2022).

Table 1: Current virtual fencing systems and trials.

Virtual fencing system	**Positioning**	**Control emitting cues in relation to animal's position to the fence line**	**No. studies**	**Tested animals (No. studies)**
eShepherd (Gallagher, Australien)	Integrated GPS	automated	22	Cattle (20), Sheep (3)
Boviguard (by Agrifence)	Induction wire	automated	1	Cattle (1)
Nofence (Nofence, Norway)	Integrated GPS	automated	6	Goat (1), Cattle (3), Sheep (2)
Fleck2 wireless sensor network /WSN) device	External GPS	Manually by remote device	2	Cattle (2)
Invisible Fence	-	Manually by remote device	2	Goats (2)
Garmin TT15 (Garmin Ltd., Kansas, KS, USA)	Integrated GPS	Manually by remote device	8	Sheep (8)
Vence (Vence Corp. Inc. San Diego, CA)	Integrated GPS	automated	3	Cattle (3)
Halter (Halter, New Zealand)	Integrated GPS	automated	0	-
Other prototypes (not released)	-		4	Cattle (3) Sheep (1)

Digital herding by drones and robots

A ground-breaking developmental step started from the Sheepdog Project in 1995. Here, wheeled robots gathered in and guided a flock of ducks to a specific location. Moreover, heart-rate and blood tests showed that the animals were less stressed by the robot than they were by either a human or a stuffed fox (Vaughan et al. 1998). During the last thirty years only a few studies have been published. Developments of digital herding technologies are mainly based on ground wheeled or legged robots that guide animals through coloured bars on a small vehicle (e.g., 'SCRUPAL' – Evered et al., 2014) or gingerly collision by bigger sized ground robots (e.g., 'Rover' – BBC report; 'SwagBot' – IEEE Spectrum). Evered et al. (2014) recorded the distance from the robot SCRUPAL' to a sheep flock when the nearest sheep first became alert to the presence of the slowly approaching robot and the distance at which the sheep began to move away from the robot and tested for three trials. They found that the alert distance and flight distance dropped from the first trial to the third trial. The flight distance during the third trial for robot herding was similar to those for vehicle herding. However, all these herding robots are still in the prototype stages. Among hurdles in off-road capability for various difficult terrains, there is a current lack of sufficiently efficient algorithms to monitor, assess and adapt robot-animal-interactions and external disturbances for autonomous and remote control of herding for both ground-based robots and drones (Li et al. 2022). For guiding cattle to a designated location, the robot needs an integrated algorithm that continuously monitors, assesses, and adapts to the three main principles in terms of collision avoidance, velocity matching and centering to the nearby members of the flock or herd according to Reynold (1987). Moreover, cattle have individual zones of neutral perception, perception, motion, flight or attack, which must be recognized by robots. Cattle want always to see who or what guides them, so robots must always adjust their position to the cattle' field of vision. Cattle follow other herd members, so robots must induce targeted motion for a core group.

Several tech-savy and innovative livestock farmers from the Australian Outback to Irish countryside already use drones to move their sheep (e.g., Holley, P., 2019 – The Washington Post) or cattle (Brady, H., 2020 – National Geographic) herds across the farmland, which is a relatively cheap alternative to farm workers, cowboy, sheepdog or even helicopter. Furthermore, in large rangelands or inaccessible terrains drones have many superior advantages regarding their speed and manoeuvrability compared to human or robotic herders. Recent studies reported similar success of drones to move wild horses into a trap for population control treatments compared to capturing by helicopters. Moreover, capturing by drones is proposed to benefit both animal and human safety and welfare (McDonnell and Torcivia 2020). For reindeers, herding by helicopters revealed no effects on stress indicators such as blood metabolites or muscle glycogen content (Wiklund and Malmfors 1996). One recent study by Brunberg et al. (2021) investigated the response in a flock of sheep to the presence of a drone compared to a human or a dog. They found that sheep flocks exposed to drones spend more time moving around compared to those exposed to more familiar humans and dogs spending more time with grazing. This demonstrates that a gentle and stepwise habituation to flying drones as herding tools is just as important as for human herders or sheepdogs. In general, scientific studies dealing with impacts of digital herding on animal welfare do not exit so far (Herlin et al. 2021).

Conclusions and/or Implications

Digital herding technologies are likely to revive outdoor grazing and to transcend existing paradigms of grazing management. Opportunities to provide and prevent access of grazing livestock to any subareas of the entire pasture, farm, or landscape at any spatial and temporal scale are enormous. Nevertheless, implementation of digital herding will only be as good as the knowledge and skills of farmers who operate them. However, several hurdles need to be solved for broad application in grazing systems. These hurdles include technical improvements, economic and operational preconditions for on-farm application, and further research in efficiency and animal welfare for diverse grazing regimes.

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References

Aaser, M. F., Staahltoft, S. K., Korsgaard, A. H., Trige-Esbensen, A., Alstrup, A. K. O., Sonne, C., ... & Linder, A. C. (2022). Is Virtual Fencing an Effective Way of Enclosing Cattle? Personality, Herd Behaviour and Welfare. *Animals*, *12*(7), 842.

Anderson, D. M., Estell, R. E., Holechek, J. L., Ivey, S., & Smith, G. B. (2014). Virtual herding for flexible livestock management–a review. *The Rangeland Journal*, *36*(3), 205-221.

Birrell, S., Hughes, J., Cai, J. Y., & Iida, F. (2020). A field-tested robotic harvesting system for iceberg lettuce. *Journal of Field Robotics*, *37*(2), 225-245.

Boyd, C. S., O'Connor, R., Ranches, J., Bohnert, D. W., Bates, J. D., Johnson, D. D., ... & Doherty, K. E. (2022). Virtual Fencing Effectively Excludes Cattle from Burned Sagebrush Steppe. *Rangeland Ecology & Management*, *81*, 55-62.

Brunberg, E., Eythórsdóttir, E., Dýrmundsson, Ó. R., & Grøva, L. (2020). The presence of Icelandic leadersheep affects flock behaviour when exposed to a predator test. *Applied Animal Behaviour Science*, *232*, 105128.

Evered, M., Burling, P., & Trotter, M. (2014). An investigation of predator response in robotic herding of sheep. *International Proceedings of Chemical, Biological and Environmental Engineering*, *63*, 49-54.

Campbell, D. L., Lea, J. M., Keshavarzi, H., & Lee, C. (2019). Virtual fencing is comparable to electric tape fencing for cattle behavior and welfare. *Frontiers in veterinary science*, *6*, 445.

French, P., O'Brien, B., & Shalloo, L. (2015). Development and adoption of new technologies to increase the efficiency and sustainability of pasture-based systems. *Animal Production Science*, *55*(7), 931-935.

Hamidi, D., Grinnell, N. A., Komainda, M., Riesch, F., Horn, J., Ammer, S., ... & Isselstein, J. (2022). Heifers don't care: no evidence of negative impact on animal welfare of growing heifers when using virtual fences compared to physical fences for grazing. *animal*, *16*(9), 100614.

Herlin, A., Brunberg, E., Hultgren, J., Högberg, N., Rydberg, A., & Skarin, A. (2021). Animal welfare implications of digital tools for monitoring and management of cattle and sheep on pasture. *Animals*, *11*(3), 829.

Horn, J., & Isselstein, J. (2022). How do we feed grazing livestock in the future? A case for knowledge-driven grazing systems. *Grass and Forage Science*, *77*(3), 153-166.

Li, X., Huang, H., Savkin, A. V., & Zhang, J. (2022). Robotic herding of farm animals using a network of barking aerial drones. *Drones*, *6*(2), 29.

Lomax, S., Colusso, P., & Clark, C. E. (2019). Does virtual fencing work for grazing dairy cattle?. *Animals*, *9*(7), 429.

Marini, D., Cowley, F., Belson, S., Lee, C., & Wilson, C. (2022). Comparison of virtually fencing and electrically fencing sheep for pasture management. *Animal Production Science*.

McDonnell, S., & Torcivia, C. (2020). Preliminary proof of the concept of wild (Feral) horses following light aircraft into a trap. *Animals*, *10*(1), 80.

Reynolds, C.W. Flocks, herds and schools: A distributed behavioral model. In Proceedings of the 14th Annual Conference on Computer Graphics and Interactive Techniques, Anaheim, CA, USA, 27–31 July 1987; pp. 25–34.

Sonne, C., Alstrup, A. K. O., Pertoldi, C., Frikke, J., Linder, A. C., & Styrishave, B. (2022). Cortisol in Manure from Cattle Enclosed with Nofence Virtual Fencing. *Animals*, *12*(21), 3017.

Umstatter, C. (2011). The evolution of virtual fences: a review. *Computers and Electronics in Agriculture*, *75*(1), 10-22.

Vaughan, R., Sumpter, N., Frost, A., & Cameron, S. (1998, August). Robot sheepdog project achieves automatic flock control. In *Proc. Fifth International Conference on the Simulation of Adaptive Behaviour* (Vol. 489, p. 493).

Verdon, M., Langworthy, A., & Rawnsley, R. (2021b). Virtual fencing technology to intensively graze lactating dairy cattle. II: Effects on cow welfare and behavior. *Journal of dairy science*, *104*(6), 7084-7094.