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Digital Twins with Application of AR and VR in Livestock Instructions

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Abstract: The paper considers the opportunities offered by the development of virtual and augmented reality as a modern approach to be included in education in the field of animal husbandry. The potential of different augmented reality (AR) and virtual reality (VR) tools and environments for use in different learning modes is well known and often explored. There are many examples of the application of VR/AR in medical education and human health. Therefore, there is no reason why this should not work to improve veterinary science education or to improve the professional experience of breeders – the technology is available, and it is all a matter of appropriate applications. The application of technologies for 3D visualization and modelling with haptic and sensory capabilities for feedback - AR/VR - in the field of veterinary science and animal husbandry is discussed and analysed. Using augmented reality and virtual reality tools to enhance the professional experience of breeders is considered. Improving animal welfare efforts through AR and VR is examined. The framework of this study lies in the proposed in the paper integration of the Five-Domain Model with the concept of Precision Livestock Farming. Methodology of digitalization of education and creation of new digital AR/VR educational resources in the field of animal husbandry is suggested.

Keywords: *animal welfare, augmented reality (AR), digital twins*, *PLF, simulation environment, virtual reality (VR).*

1. Introduction

We are living in a time of rapid advancement in terms of the capabilities and economic viability of augmented reality (AR), virtual reality (VR), multi-user virtual environments, and various forms of mixed reality (MR). These new media seem to open up extraordinary opportunities for the enhancement of motivation and learning across a range of subject areas, student developmental levels, and educational settings. With the development of practical and affordable virtual reality and mixed reality, people now have the chance to experience immersive learning both in classrooms and informally in homes, libraries, and community centres [1].

Both VR and AR have many different applications in the learning process, and they come from the specifics of both technologies – virtual reality offers the simulation of an entirely computer-generated perceptive experience while augmented reality is the integration of digital information with the user's environment.

While VR allows learners to experience different spaces from without ever leaving the classroom, augmented reality can be considered "as a dynamic and interactive didactic tool, which contributes to transform spaces, times and modes of learning thanks to the fact that school laboratories and classrooms start to be widely equipped with suitable technological infrastructures" [2].

The potential of different VR/AR tools and environments for using in different modes of learning is well known and commonly explored. There are many examples for VR/AR application in medical education and human healthcare [3]. Therefore, there is no reason why this should not work to improve veterinary science education or to improve the professional experience of breeders – technology is available and it is all a matter of appropriate applications.

Humans have been raising cows for eight thousand years. Many of animal husbandry practices are based on limited observation of animal's behaviour. Recently, technologies are increasingly entering animal husbandry. This is due to several reasons:

- the technology development;
- the growing number of animals on farms to meet rising food needs of human population;
- the current trend of increasing urban population at the expense of people in rural areas.

As a result of these trends, digitalization is entering livestock. Digitalization provides opportunities to create new educational resources in the field of animal husbandry, based on research results and large volumes of collected data on animals. The greatest potential lies in individual monitoring and analysis of animals, called Precision Livestock Farming (PLF), where various devices and sensors are used for continuous and automatic monitoring of key livestock performance indicators in animal health, productivity, and environmental load.

The trend towards intensifying livestock systems is increasing productivity, but it can also have adverse effects on animal welfare and health and increase the risk of rapid and widespread disease outbreaks. The technology-oriented approaches to monitor animals' welfare can be supplemented with digital representations of the animals with tools for Augmented and Virtual Reality (digital twins). Breeder confidence comes from learning and experience. Augmented reality is also about experience. Augmented reality is based on a concept of creating an experience in accordance with theoretical evidence, that created experience stays for a whole lifetime. Implementing this into the education practice can really transform the experience of learning. Moreover, because this experience is gained in a safe environment, augmented reality can be especially beneficial for novice breeders.

Improving animal welfare efforts through VR/AR is another area where the strengths of these technologies stand out. Good knowledge of the animals, the environmental requirements they have, as well as their behaviour and ways to avoid pain, are key to their welfare. An important role in the overall approach to animal welfare is the Five Domains Model.

The article considers the opportunities offered by the development of virtual and augmented reality as a modern approach to be included in education in the field of animal husbandry. First, we recall what does the Five Domains Model for animal welfare assessment mean. Then we use Precision Livestock Farming (PLF) concept to construct a base for designing various models of digital animals and farms. A discussion of AR and VR applications is provided. Using all these approaches allows us to define a methodology of digitalization of education and creation of new educational resources in the field of animal husbandry.

2. Background

2.1. Five Domains model for animal welfare

Animal welfare is of great importance today and every farm should keep this in mind. The fundamental scientific structure for assessing animal welfare is the Five Domains Model.

The five domains model for animal welfare assessment is a "guidance on how to evaluate the negative and/or positive impacts of human behaviour on animal welfare" [4]. These domains of the model are nutrition, physical environment, health, behavioural interactions, and mental state (Fig. 1).

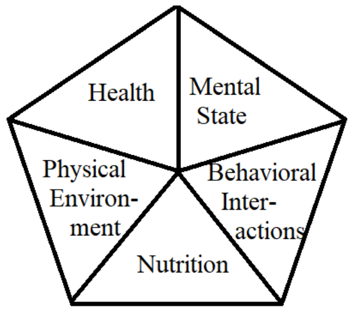

Fig. 1. The five domains model for animal welfare assessment.

The model covers intense studies on the human–animal interactions and considers positive or negative welfare impacts from these contacts. The Five Domains model is a tool for measuring and evaluating animal welfare. The Five Domains animal welfare assessment model is a kind of guide on how to assess the negative and positive impacts of human behaviour on animal welfare.

The European Union Strategy for the Protection and Welfare of Animals stated as its objectives animal welfare education. Within the Strategy "students are seen as the most obvious target, and it was generally believed that animal welfare would be better understood if it were introduced into the curriculum at an early age preferably combined with visits to commercial farms" [5]. However, a visit to a commercial farm may be inappropriate for several reasons such as financial costs, time consumption, animal anxiety or medical reasons. And here technology can be useful, as augmented reality brings livestock into every place and can project images of 3D objects around.

2.2. Precision livestock farming

The main idea of Precision Livestock Farming (PLF) is to give "better information to the farmer on the animals by exploiting the known principles of process engineering to provide a level of automation" [6].

PLF is a set of farming practices, including the use of advanced technologies, to deliver better results in livestock farming. Those results can be quantitative, qualitative and/or addressing sustainability, and the technologies involved include cameras, microphones, and other sensors for tracking livestock, as well as computer software. PLF is a tool for management of livestock by continuous automated real-time animal monitoring to improve production/reproduction, health and welfare, and environmental impact.

We think that another dimension can be added to the PLF technology by creating visual 3D representation of the Digital Twins of the animals in a farm.

The framework for this investigation integrates the Five domain model with PLF.

2.3 AR/VR

Augmented reality is a practice, where computer vision is used to place, or "augment" virtual objects and scenes on top of the real world. The augmentation is said to be complete when the user-placed objects and scenes interact with the objects and the environment in the real world [16]. Virtual reality is computer-generated surroundings which provides a real-life feel having all the senses in a virtual way which is being used broadly in entertainment, medical science, military and so on [17]. The Table 1 gives a short comparison of these technologies.

Table 1.

	VR	AR
Tools	VR spectacles	Smartphones, AR systems
Properties	An entirely computer-generated reality is created	Adds images or interactive virtual elements to the real world
Pros	Realistic sensations and visual experiences	Especially suitable for simulations in the field of STEM
Cons	Potential health risk with prolonged use	AR glasses/special display are needed

3. Use of VR and AR tools in veterinary science training and animal husbandry

3.1. VR/AR tools in veterinary science training

Augmented reality has the potential to combine the real with the virtual world. This technology allows "for both teachers and students to see information in a real environment that would otherwise be impossible to show" [7]. Thus, many scientific concepts can be visualized what have been impossible before to illustrate clearly [11], [12].

There are different VR/AR anatomy training tools for veterinarians. Among them are:

- EZ Augmented Anatomy – allows scanning of a 3D physical model using the Augmented Anatomy app.
- Haptic Cow & Haptic Horse (https://www.virtalis.com/products/haptic-cow-haptic-horse) – the systems draw on virtual touch, or haptics, and enable students to carry out virtual rectal and abdominal examinations (Fig. 2).

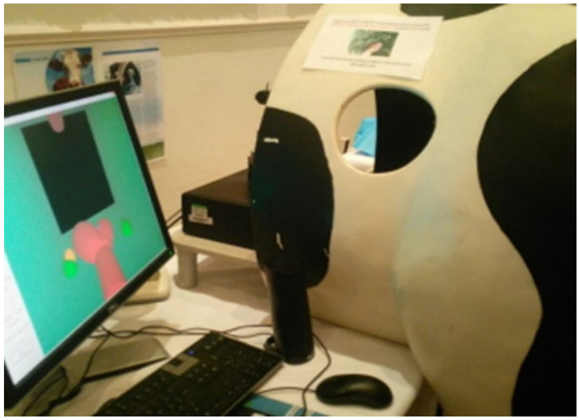

Fig. 2. Haptic Cow & Haptic Horse

- EasyAnatmoy (https://easy-anatomy.com/stu/) – allows virtual dissection and exploration outside the lab, as well as to peel away layers, hide components, isolate regions, and visualize the spatial relationship between anatomical structures (Fig. 3).

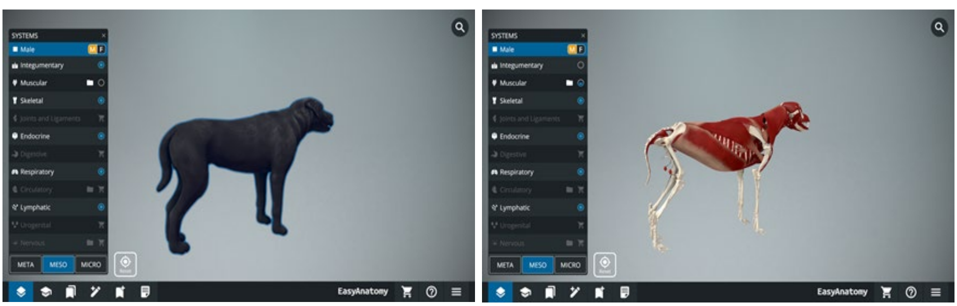

Fig. 3. Integumentary vs Muscular-Skeletal-Endocrine-Respiratory-Lymphatic views of a dog.

- QVIREA Initiative by EQAsce and AnimaRES – This tool is designed for learners to acquire knowledge to eliminate pain in piglets (Fig. 4). "The students shall no longer only read and understand information: Using the new AR-tool, nerve tracts, muscles, the cardiovascular system, and the respiratory system of a virtual piglet can be made visible. The user can place the piglet everywhere, turn it, move it, and receives information about important aspects by using his/her tablet or smartphone" [8].

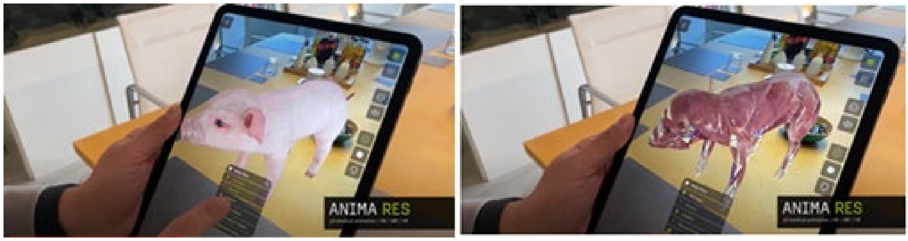

Fig. 4. 3D medical animation AR/VR/MR
[https://www.youtube.com/watch?v=GGPmY5Ax-1Q]

Fig. 5. Canine Anatomy VR Trainer

- Canine Anatomy VR Trainer by GTAFE (Fig. 5) – this is a powerful teaching tool for veterinary students, which offer practical training of the canine anatomy. The trainer is used in combination with zSpace® [https://zspace.com/technology] – an all-in-one solution that "combines elements of AR and VR to create lifelike experiences that are immersive and interactive."

3.2. AR application in animal husbandry

Economic pressures continue to mount on modern-day livestock farmers, forcing them to increase herds sizes in order to be commercially viable. The natural consequence of this is to drive the farmer and the animal further apart. However, closer attention to the animal not only positively impacts animal welfare and health but can also increase the capacity of the farmer to achieve a more sustainable production. State-of-the-art precision livestock farming technology is one such means of bringing the animals closer to the farmer in the facing of expanding systems. Contrary to some current opinions, it can offer an alternative philosophy to ‘farming by numbers’ [6].

In the PLF the data, collected by monitoring of the animals are used to build their “digital representations” or “digital twins” [9]. A digital twin can be described as a digital replica, a virtual model, of a real-world entity. The digital twin simulates the physical state of the real object in real environment by exchange of data. Thus, both the state and the behaviour of the real object (the animal in our case) can be simulated. This allows for better prediction, optimization and decision-making process. In this perspective, the development and implementation of the digital twin in modern animal farming can be explored.

Augmented realty can be very successfully combined with the PLF set of farming practices and the “digital twins” concept. One of the ways is to use it to compare the anticipated and actual animal behaviour.

By observing the activity of pigs and chickens and recording vital signs through sensor technology, farmers can design novel solutions using digital twins to anticipate and prevent damaging behaviours, such as tail biting and feather pecking. Using real-time data and simulations, farmers can predict how pigs and chickens will respond environments, as well as to changes in barns, pens and populations. Augmented reality technology allows comparisons between predicted behaviour and actual behaviour, providing insight to improve the welfare of livestock [9].

One particular application that uses PLF and brings the AR technology into the dairy farm is Nedap CowControl™ (Fig. 6).

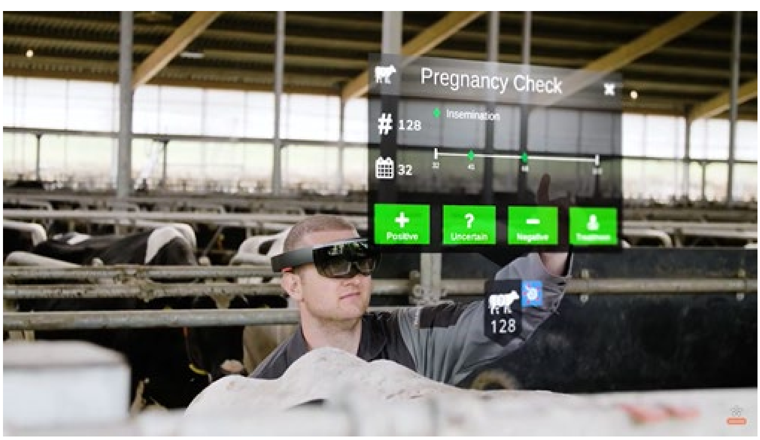

Fig. 6. Augmented Reality - Nedap CowControl

Nedap CowControl™ is the all-in-one dairy herd monitoring and management system. It helps to maximize herd performance and farm efficiency by boosting reproduction results, cow health, labour efficiency and farm management.

4. Methodology of AR/VR digitalization in the field of animal husbandry instructions

Data gathered as a result of implementation of PFL allows to create digital twins. In this way education will be related to PLF and attention can be paid to each element of Five Domain Model.

The PLF and the Internet of Things (IoT) reveal opportunities to create value from the data collected. IoT devices in smart farms gather heterogeneous data ranging from audio and video to sensory data. The value of data increases when (un)structured data is processed, enriched and analysed to create useful information.

Different information sources in IoT provide diverse types of data. These information sources come from the physical nature of the source of the data, which is collected and processed:

- scalar measurements,
- time series,
- samples,
- signals,
- images,
- videos, etc.

Data processing and model creation is based on IoT and cloud computing together with methods of Artificial Intelligence (AI) and machine learning algorithms as integral part of PLF. Using of cloud computing capabilities enables complex problem solving and decision support [13]. It is noticed that very often from one solved problem with IoT it turns out that new problems can be solved.

Visualization of AR/VR modules for e-Learning can be supplemented with tools organizing knowledge content which is relevant knowledge of learners [10], [18]. So, it is possible to reorganize and to offer and divide the learning content for different groups of users with various volumes of experience. Experience - this is another name for the mistakes we accumulate.

The schematical view of the proposed methodology is shown on Fig. 7.

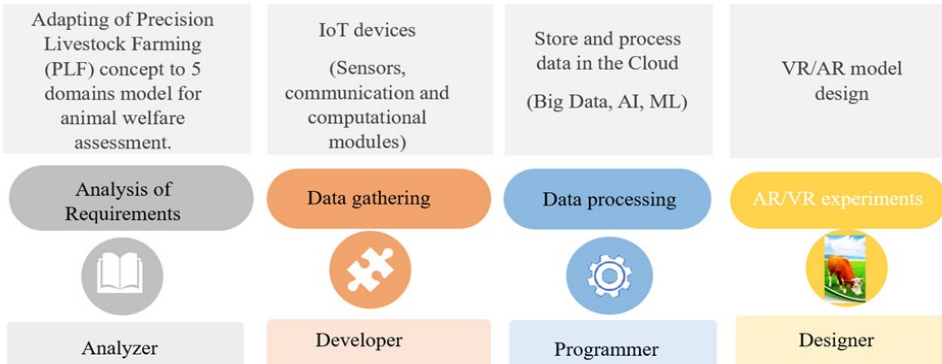

Fig. 7. Methodology of creation of new digital AR/VR educational resources in the field of animal husbandry

5. Conclusion

Digital twins in animal husbandry are software modules, which convert collected data into AR/VR model with sufficient accuracy. Created from big amount of PLF data AR/VR educational resources can give additional information about animals even to professional breeders. A 3D virtual model of the barn and animals in real time are created with showing their exact location and based on data collected from IoT devices. The data collected is based on the Five Domain Model. These digital resources provide faster learning in safe environment and can be used with different purposes from veterinarians, breeders and students. AR/VR are working also as humane teaching methods instead harmful educational animal use [14]. Biologists and computer scientists can benefit greatly from deepening interdisciplinary research in AR/VR/MR applications [15]. AI software monitors the values of the data collected and alerts when values are outside pre-set intervals. In addition, the software provides information on possible problems that may arise from the measured deviations, as well as on the actions that can be taken as soon as possible to solve the problem. From another side using of large volumes of PLF data together with AI and machine learning algorithms could help to discover hidden dependences in animal behavior and thus contribute to the development of animal science.

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