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**Smart Glasses for Augmented Reality as a Digital Tool in
Livestock Farms: Investigation of Operating Performances,
Usability Level, and Farmers' Acceptance**

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CHAPTER 1

General Introduction

1. Introduction

Future estimates of world population size evaluate 8.6 billion earth's inhabitants in 2030 and 9.8 billion in 2050. Most will settle in cities rising the rapid urbanization process started approximately in the '60s. Around 2030 the world population distribution in urban and rural areas will be 60 percent and 40 percent respectively, further widening the gap between commodities producers and consumers. In addition, increasing demand for the key commodities (cereals, meat, fresh dairy) will occur either for the world population and per capita consumption growth. The annual demand for animal products, e.g., meat (beef, sheep, poultry, pork), dairy products, etc., is expected to grow in the range of 1-2 percent per year until 2030 (FAO, 2018). Whereas, in the European Union (EU-27) livestock productions have a steady increasing trend since 2004. Concerning meat productions, it was estimated that in 2020 the EU produced 43.9 million tons of meat (pig 52.4 %, poultry 30.9 %, bovine 15.5 %, sheep/goats 1.1 %), whereas the amount of milk, in the same year, was estimated to be 160.1 million tons of which more than 90 % cows' milk (Eurostat, 2020).

The livestock sector represents one of the most important production sectors in the European rural areas. The last decade has been facing with several issues related to its economic (productivity, efficiency), social (animal health and welfare), and environmental (greenhouse gasses, soil use, biodiversity) impacts. Nevertheless, the livestock production sector has been able to provide important services and benefits. The magnitude of the impacts and benefits has been related also to the different typology of European livestock production areas, e.g., low-grassland regions with high livestock density, high-grassland regions with different livestock density (low, medium, high), or, both crop and livestock productions regions (Dumont et al., 2016; Leip et al., 2015). Another important challenge for livestock farming is the sustainable increase in animal productions (milk, meat, eggs). It is therefore necessary reduce as much as possible the impacts of livestock farming on the environment, while improving animals' productivity. A rational use of resources and inputs (agricultural land use, feed, antibiotics, energy, etc.), and a reduction of non-food outputs (less manure, food waste reduction, less GHG)

is required (Berckmans, 2017). Other issues have been exerting pressure on the livestock sector, such as food security, safety, and quality; lower food price and farmers' income; animal health and welfare, underlining how the livestock production sector has been challenged on multiple levels (Hartung et al., 2017). In addition, a reduced generational turnover is taking place in the farms, and there is a lower number of farmers with larger herd to be managed (Berckmans, 2017).

The farms digitalization process and the increasingly spreading of digital technologies, could provide a significant help to the livestock farming to mitigate their impacts and to solve challenges (Klerkx et al., 2019; Neethirajan and Kemp, 2021). During the years, many innovation technologies have been applied to livestock to help farmers manage the herd and the farm precisely, efficiently, and effortlessly, enhancing animal performance, farmers' working conditions, and the overall farm profit. There is currently on the market a wide range of digital technologies suitable for precision livestock farming (PLF) applications. It is possible to distinguish between monitoring technologies, attached to the animals or in the barn (sensors, actuators, cameras, etc.), and management software technologies, e.g., notice applications, farm management systems, digital platforms (Birner et al., 2020; Tedeschi et al., 2021). All these tools can be backed by the broadband connections, mobile devices, and the Internet of Things. One of the first developed PLF technology, especially suited for the dairy sector, was the automatic milking system that transformed and improved the milking routines management (John et al., 2016; Steeneveld et al., 2012).

Although the introduction of digital technologies within livestock farms could bring unquestionable benefits, new challenges arise related to the use of these technologies by farmers e.g., farmer self-sufficiency, rational use of data in driving decision-making, user-friendly device interface, data property, low data standardization (Halachmi et al., 2019; Neethirajan and Kemp, 2021). Despite the strengths and opportunities shown by digital and precision management technologies within the livestock farms, there is not yet a full and wide use by farmers. The wide acceptance and use of digital technologies might be influenced by economical, socio-cultural factors, and logistical, infrastructural issues (Abeni et al., 2019).

1.1. Digital Farming

Digital agriculture is a new concept of farm management, essentially defined as the use of new and advanced technologies that could be integrated into a single system to help farmers to increase food production (Trendov et al., 2019a; Klerkx et al., 2019). The term digital farming has been usually used as a synonym of smart farming or Agriculture 4.0. Agriculture 4.0, therefore, represents the fourth step of the development of the agricultural system. Starting from an agriculture characterized by a high labor demand in the early 1900s (Agriculture 1.0), we moved to a first revolution of the agricultural system, also known as the “Green Revolution” that with the introduction of new agronomic practices (fertilizers, pesticides, machinery) led to an excessive increase of agricultural yields (Agriculture 2.0). Agriculture 3.0 begins with the introduction of the GPS technology for crops precise management and crops operations control, managing the farm precisely (precision farming), thanks also to the introduction of telecommunication systems and farm management software (Cema, 2017). Nowadays, society is pervaded by digital and smart technologies that influence humans’ daily life. The same happens in the agricultural context especially in developed countries. As in previous agricultural phases, Agriculture 4.0 has been also influenced by the socio-cultural and economic context, which led to the so-called digital revolution in agriculture (Cema, 2017; Trendov et al., 2019b).

Digital farming consists of the use of information and digital technology (such as networks, hardware, software, cloud computing, sensors, actuators, automation) in conjunction with farm and production units’ data (field, crops, animals), to manage animals, precisely, punctually, and efficiently. The general aim of introducing these technologies in the livestock farm is to increase productions (milk and meat yield), animal health status (SCC monitoring, sub-clinical mastitis), and animal-human welfare (thermal stress, reduction of hours per day in the barn), also improving management strategies taking data-driven decisions (Halachmi et al., 2019).

In the last years, the digitalization process has been driven by the cost reduction of many electronic components (microprocessors, sensors, actuators), the improvement of the networks, the increased mobile devices computational power, the digital skill implementation, etc. (Cema, 2017; World Bank, 2019; Birner et al., 2020). The overall digitalization degree in many professional and urban contexts has been higher and relatively faster than in other sectors, such as agriculture, where the implementation of the digital technologies was slower (Manyika, 2018; World Bank, 2019). In the Italian livestock sector, the adoption rate of IT management solutions for the livestock in 2020 was 38.5%, indicating that more than half of livestock farms did not use digital solutions. The gap widens when company size and geographical location (North > Central > South Italy) are considered. Moreover, the most important digital solutions used by the Italian livestock farmers were IT herd management systems (cattle, pigs, sheep, goats) and remote animal identification systems for sheep and goats (Istat, 2021).

Several factors and challenges have been influencing the digital and smart technologies implementation in the livestock domain. Some issues might be directly related to the farmers, (digital literacy, attitude, basic digital skills, self-sufficiency) or the technology itself (data contents, friendly user interface). Furthermore, the initial investment required to get certain technologies (automatic milking system, sensors), or the maintenance and support costs might represent a barrier to the deployment (Kritikos, 2017; Epi-Agri, 2020; Vaintrub et al., 2021). The limited broadband connection in the rural areas, the data ownership, and user's rights and privacy are other limits (World Bank, 2019).

The importance of the digital technologies in agriculture has also been highlighted by the growing number of firms that are investing in the development and marketing of digital and smart solutions for the farming sector. The main types of firms involved are multinational agricultural (Bayer, Deere & Company, etc.) software companies (Microsoft, IBM, etc.), machinery/tools companies not strictly related to agriculture (Bosch, Allflex, DJI, etc), and start-ups (Birner et al., 2020). Unfortunately, too many companies mean different management systems, different interfaces, and likely, limited

software compatibility, representing a stumbling block to easy use by farmers (Drewry et al., 2019).

1.1.1. Precision Livestock Farming and Technologies Overview

The cornerstones on which Precision livestock farming (PLF) is based are digital technologies and smart tools that may have been specifically developed or adapted for livestock purposes (Halachmi et al., 2019; Neethirajan and Kemp, 2021; Vaintrub et al., 2021). The PLF was created to allow farmers to have immediate knowledge of the physiological, behavioral, production, and reproduction status of each animal and to improve the performances both in quantity and quality terms (Wathes et al., 2008). In literature, PLF is defined as a livestock farm management system based on automatic and continuous monitoring of production parameters (e.g., live weight and growth, milk yield and quality), reproduction parameters (estrus, parturition prediction), health parameters (sub-clinical mastitis or lameness outbreaks) and animal welfare parameters (environmental conditions, space monitoring), also allowing to evaluate the environmental impact of livestock activities (Berkmans, 2014; Berkmans, 2017). This management system can be applied to monitor the smallest production units, which can vary depending on the raised species (e.g., cattle, buffalo, sheep, goats) and the technology employed (Halachmi and Guarino, 2016). Some PLF systems can monitor and correlate the external environmental factors, such as temperature, humidity, and ventilation, which might affect the production and reproduction, as well as the welfare status, of the species being reared (Hostiou et al., 2017). These collectible data can be used to improve the decision-making process increasing the farm management precisely. In fact, PLF aims to provide real-time warning, i.e., on a specific animal on the farm, allowing the farmer to react promptly to solve the problem (Berkmans, 2017).

The forerunner PLF technologies already used in the 1980s for livestock monitoring were individual electronic milk meters and cow behavior-based estrus detectors (Hostiou et al., 2017; Halachmi et al., 2019). Currently, tools such as 2D and 3D video cameras,

thermal cameras, microphones, can be used with different types of sensors (accelerometers, Radio Frequency IDentification, ruminal bolus) to punctually manage individual animals (cattle, buffalo) or groups of animals (cattle, sheep, goats, poultry). Video cameras and thermal cameras can be used to estimate the animal live weight, and the Body Condition Score (BCS), which in this way could be standardized by eliminating or reducing the subjective error of one or more operators (Halachmi et al., 2013; Spoliansky et al., 2016). Moreover, the pig food ingestion, and their welfare could be measured by applying specific algorithms to sound analysis (Benjamin and Yik, 2019). Triaxial accelerometers, collars, and ear tags can be used to detect the arise of lameness or disease and to monitor the feeding and physiological behavior of animals, (for example, rumination time or onset of estrus). In addition, global positioning systems (GPS) can be used to optimize herd or flock management in the pasture (Halachmi et al., 2019). If the data provided by different wearable sensors are interpolated, the level of information obtained increase. Thus, combining data on position (GPS) and animal movement (triaxial accelerometer, collar, pedometer), results on the individual behavior (e.g., walking, resting, feeding) can be gained (Williams et al., 2016).

Other applications are the detection of diseases such as sub-clinical mastitis or ketosis through real-time analysis of milk composition (abnormal fat-protein ratio) and the ruminal behavior. An alternative method for the inflammation detection, caused for example by injuries or infections on animal legs (lameness detection), or mammary gland (detection of subclinical mastitis), is given using thermal images analysis to detect the animal body temperature (Halachmi et al., 2019). The advantages of this method are that the results can be obtained without necessarily coming into physical contact with the animals, reducing the risks of diseases/infection transmission, and of influencing the animals' response (Berckmans, 2017). However, there are some physical-logistical or physiological-environmental limitations to the use of thermal cameras to monitor animal health and welfare that may affect or prevent image detection. Many of the wearable sensors to animal monitoring (e.g., accelerometers, collars, and GPS) have been more applied to large animals such as cattle and buffalo, than small ruminants, since the investment is more justified by their higher productivity. For sheep and goats, on the other

hand, monitoring systems are mainly applied at the flock level because of the lower cost-effectiveness in purchasing individual devices for lower production value animals (Halachmi et al., 2019).

Even though, PLF and digital solutions are mainly adopted and commercially available to the dairy sector (Groher et al., 2020), there are several PLF solutions for extensive small ruminants farming, including electronic identification system (EID) which is of central importance in connecting many other PLF technologies (Vaintrub et al., 2021).

These devices and sensors generate countless volumes of data (climatic, environmental, productive, reproductive, animal behavior, etc.), especially on large farms. It has been highlighted how an appropriate visualization of farm data or even of individual production units can improve farm productivity also in terms of animal welfare and emissions reduction. Therefore, it is essential the use of detection sensors as well as an appropriate visualization and interpretation system of the data (Van Hertem et al., 2017). These sensors and devices should not, however, replace the intuition and knowledge that the farmer has about his farm, but should be considered as a valuable tool to support farmers' decision-making process (Berkmans, 2014). In fact, the livestock farming context and the biological processes are quite complex to completely replace farmers with digital technologies. The technology could work together with the farmers to save money and work time, and to improve the potential of the livestock species (Berckmans, 2017).

1.2. Augmented Reality and Smart Glasses main concepts

The augmented reality (AR) matches all those technologies that allow to combine and align virtual elements with the physical objects on the real-world view. The computer-generated elements can be texts, shapes, icons, images, videos, sounds, etc. aiming to provide overlaid information (augmenting) on a specific item. AR adds information into reality without completely replacing it as is the case of virtual reality systems (Caudel and Mizell, 1992; Azuma, 1997; Azuma et al., 2001).

Any device with a camera, a screen, and sufficient computation power could implement AR solutions (Azuma et al., 2001; Fraga-Lamas et al., 2018). Another device that allows the implementation of the AR are smart glasses (SG), also called AR headsets or AR glasses. Different from smartphone and tablet (handheld), AR glasses are hands-free systems, since the wearers can, manage the AR contents without the use of hands (Szajna et al., 2020). SGs can be seen as minicomputers worn like normal glasses and equipped with a display that replaces the glasses lens where the AR contents are projected. AR solutions provided on mobile devices belong to the mobile augmented reality (MAR; Chatzopoulos et al., 2017). The user interface of SG, in relation to the operating system, is like the smartphone interface (icons, apps, drop-down menu). Some issues must be fixed for the AR headset in comparison to smartphones. In fact, SG have a smaller display size, input interface, and restricted computational power, other than a short battery life. The main elements that differentiate an SG augmented reality system from a tablet or smartphone are the display systems, and the interaction control systems (Chatzopoulos et al., 2017; Lee and Hui, 2018).

The display system can be an optical see-through system consisting of a semi-reflective or semi-transparent surface where the computer-generated contents are projected and aligned with the user's eye without occluding the real-world view (Syberfeldt et al., 2017; Lee and Hui, 2018). A problem related to this visualization system concerns its use outdoors or in too bright places that could influence the quality of virtual element visualization (Lee and Hui 2018). The agricultural working environment could affect the outdoor use of this type of SG. In contrast, the video see-through system is principally composed of a video camera for the real-world image acquisition and a screen where the augmented information, blended with the real environment, is shown (Syberfeldt et al., 2017; Chatzopoulos et al., 2017). This type of system is typical of handheld AR systems such as smartphones or tablets, but it is implemented also on AR glasses. The retinal system projects the virtual content directly on the eye of the user with a low-power laser, but it has been rarely used (Syberfeldt et al., 2017). Several methods allow interaction with the interface of an AR headset device. The main systems are tangible interaction methods (specific button, touchpad placed on

the device, joystick). Another important interaction method consists of a voice control system that allows managing the device, completely or partially through specific commands pronounced by the user. This second interaction system makes the use of SG completely hands-free, representing one of its strengths (Lee and Hui 2018).

Other common components for the AR devices, both handheld and hands-free, are cameras and sensors (accelerometer, gyroscope, magnetometer, GPS). These components are essential to implement AR solutions since allow to “recognize” the real elements to be augmented. This process corresponds to the tracking and registration system. It is possible to discriminate among three principal anchoring methods, i.e., vision-based, sensor-based, and hybrid. The first method principally involves the device cameras to detect the object and superimpose the information on it (vision-based). The AR system can recognize specific markers (QR code, template, Data Matrix) and anchor the AR information on it (Marker-based) or can recognize specific features or real objects and pose the AR content (Feature-based). The second method, on the other hand, involves the sensors (inertial, magnetic, electromagnetic, ultrasonic) of the device to detect the mutual position (object, user). Some interesting electromagnetic methods can use GPS or RFID technologies to enhance reality (Amin and Govilkar, 2015; Syberfeldt et al., 2017; Chatzopoulos et al., 2017).

1.2.1. Augmented Reality potential in Animal Husbandry

In the last decade, some researchers highlighted the potential of AR in agriculture to improve and support farmers’ work. At this regard, in the bibliography there are studies related to the use of AR system in weed identification (Vidal and Vidal., 2010), as a support to the distribution of fertilizers by tractor (Santana-Fernández et al., 2010), to provide information on vine rows (King et al., 2005) or as an auxiliary tool for farm management (de Castro Neto and Cardoso, 2017; Huuskonen and Oksanen, 2018). It has been also highlighted how this technology could be a valuable tool, complementary to others already available in PLF (Cupial, 2011).

The SG could give support to breeders or farmers providing substantial information in real-time on individual animal about its health status, productivity, stage of lactation, etc. These reports would be available while the breeder working (milking or driving the tractor) since SG allow hands-free operation. Another possible application involves the use of such technology to provide remote assistance to the farmer, who could show his point of view in real time to a technician, for example during the milking machine checking.

SGs and applications specifically designed and engineered for use in agriculture and animal husbandry are not yet available. It would be desirable, in this sense, the development of SG and/or applications able to integrate with other PLF tools eventually present on the farm, such as the implementation of data and information provided by the management software. An important step needed for the diffusion and the use of digital technologies in agriculture is related to the inter-communicability between smart and PLF technologies available on the farm, such as, for example, sensors (collars, pedometers, biometric sensors, etc.), devices (computer, mobile tool), and machinery (milking robot, mixer wagon) (Bahlo et al., 2019; Neethirajan and Kemp, 2021). Similarly, the maximum potential of SG for AR could be expressed as a result of the integration of these devices with other precision agriculture technologies and tools including the use of the Internet of Things (IoT; Phupattanasilp and Tong, 2019).

1.3. Technology Acceptance and Estimation Method

Important elements in the development, introduction, and use of information technologies in the working sphere are the final users' perceptions, satisfaction, acceptance, and their assessment. Several aspects related to the digital device or software can be measured by different tools. System acceptability, usability level, and cognitive load are some of these aspects, measured through specific standard instruments (survey, qualitative and quantitative interviews) and tests, allowing to evaluate users' opinions and the approval of the tested technology (Lewis, 1995; Venkatesh et al., 2003).

The issues of technology acceptance were studied for decades applying different theoretical models and approaches (Theory of Reasoned Action, Innovation Diffusion Theory, etc.; Venkatesh et al., 2003). The most popular and widely used model to investigate the determinants of user's acceptance or rejection of computer-based technology was the Technology Acceptance Model (TAM). This model was developed on existing general socio-physiology theory attempting investigate the user's behavior and attitude (Marangunic' and Granic', 2015). Although TAM was specifically developed to explain computer-based use behavior (Davis et al., 1989), in recent years it was applied to investigate a broad spectrum of innovation technology (Sharifzadeh et al., 2017; Rezaei et al., 2020).

As underlined by Shang et al., (2021), the factors that determine the farmers adoption intention or acceptance of precision agriculture technologies can be grouped in six categories: farm and farmer characteristics, interactions, institutions, attribute of technology, and physiological factors. Within these categories were identified the most significant factors e.g., farm size, use of complementary technology, education, age, computer use.

A branch of the compressive pattern of system acceptability is related to the usability aspect that could affect the use of the technology. Usability was defined as “the extent to which a system, product, or service can be used by users to achieve specific goals with effectiveness, efficiency, and satisfaction in a specific context of use” (ISO, 2018). According to this definition, the usability does not refer to an intrinsic feature of the tool, but to the interaction between users, product, task, and context (Kunkel et al., 1995). Practical contextualized tests, interviews and surveys are the main empirical evaluation tools. Standardized usability questionnaires were specifically designed for different computer systems, e.g., software, mobile phone app, web sites, etc. (Assila and Ezzedine, 2016). In addition, other evaluations of human-system interaction may concern the measurement of cognitive load. In fact, with the increasing complexity of computer systems and work processes, to improve or simplify the technologies, human-system interaction assessment could be used. The Task Load Index developed by NASA is a

multidimensional scale that allow to measure the workload of operators/user achieving determined activates (Hart, 2006).

1.4. Objectives of the Thesis

The main objective of the thesis was to study emerging digital technologies, such as smart glasses (SG) for augmented reality (AR), in a livestock farming context. The performances, the degree of integration into the farm, from a technical point of view, and the interactions with agricultural stakeholders were evaluated.

The thesis includes seven chapters: a general introduction; five experimental contributions; a general conclusions.

The general introduction reports the main aspect of digital agriculture with a focus on the precision livestock farming (PLF) technologies. Furthermore, the state of the art and the technical details of AR and SG are provided, also considering the farming applications. A brief state of the art on IT technology systems acceptability and usability concludes the general introduction section (Chapter 1).

The first experimental contribution (Chapter 2) concerns the preliminary investigation of the SG in a livestock farm. Specifically, the evaluations were focused on the device technical aspects testing the performances of a specific SG as a possible tool to support farmer decision-making in a perspective of precision animal management. Another type of SG, with different technical and constructive features, were stressed (Chapter 3). Moreover, a specific AR maintenance support framework was designed for the milking machine check. In the fourth chapter, three different types of SGs were compared, to assess which could be the best technical, functional, and operating characteristics of an SG for the agro-livestock domain.

Chapter 5 focused on the study of users' interaction with the AR device, evaluating the farmers' perspective in the use of SG for the identification of animals during grouping activities. The usability degree and cognitive workload required in the use of SG were measured through standardized questionnaires.

The last experimental contribution (Chapter 6) concerns the investigation of agricultural stakeholders' perceptions, beliefs, attitudes, and adoption intention of SG. Based on the scientific literature on the technology acceptance model, a specific survey was developed to test which factors might influence the intention to use SG to support farmers' activities.

Finally, a general conclusion with the main funding of the thesis work is reported in Chapter 7.

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CHAPTER 2

Exploring Smart Glasses for Augmented Reality: A Valuable and Integrative Tool in Precision Livestock Farming

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Simple Summary

Introducing new technologies in the agricultural and livestock field does not always lead to straightforward on-farm activities. Smart glasses for augmented reality are a new technology that may assist workers in many operations, allowing them to visualize, in the glasses' lens, diverse information related to a single subject (e.g., animal, plant, feed stock, machinery) or to receive assistance in real-time through video-calls. Using commercially available smart glasses, we explored their potential usefulness in livestock farms. The device was tested using all the functions available in different conditions, both in laboratory and open field environments. The results obtained highlighted the important contribution to assist workers in on-farm daily activities, thanks to the clear and rapid data visualization and to the good quality of audio-video streaming. Specifically, smart glasses enable real time file consulting, data collection, data sharing and remote assistance, all done while working hands-free.

Abstract

The growing interest in Augmented Reality (AR) systems is becoming increasingly evident in all production sectors. However, to the authors' knowledge, a literature gap has been found with regard to the application of smart glasses for AR in the agriculture and livestock sector. In fact, this technology allows farmers to manage animal husbandry in line with precision agriculture principles. The aim of this study was to evaluate the performances of an AR head-wearable device as a valuable and integrative tool in precision livestock farming. In this study, the GlassUp F4 Smart Glasses (F4SG) for AR were explored. Laboratory and farm tests were performed to evaluate the implementation of this new technology in livestock farms. The results highlighted several advantages of F4SG applications in farm activities. The clear and fast readability of the information related to a single issue, combined with the large number of readings that SG performed, allowed F4SG adoption even in large farms. In addition, the 7 h of battery life and the good quality of audio-video features highlighted their valuable attitude in remote assistance, supporting farmers on the field. Nevertheless, other studies are required to

provide more findings for future development of software applications specifically designed for agricultural purposes.

Keywords: remote assistance; QR code scanning; dairy sheep; mobile augmented reality; precision farming; head wearable device; animal feeding; animal breeding; remote learning

1. Introduction

At the beginning of the 1990s, Milgram and Kishino (1994) introduced the model of the virtuality continuum, characterized by the real environment and the virtual environment on the outer limits of the continuum. Among these limits, there is the mixed reality where real and virtual objects coexist at different levels on the continuum. Mixed reality includes augmented reality (AR) and augmented virtuality. The former is close to the real environment and the latter to the virtual world. Therefore, AR enriches the real-world vision with virtual objects whereas augmented virtuality enlarges the virtual world vision with real objects (Milgram and Kishino, 1994).

Later, the term augmented reality was associated with all those technologies that are characterized by the following three features: combine physical and virtual objects over the real environment; interact in real time; align physical and virtual objects with each other (Azuma et al., 2001). Therefore, an AR system allows the overlaying of different virtual elements, generated by a computer (text, chart, audio, video, image, etc.) over the real-world giving information about the physical elements that our senses could not provide (Azuma, 1997).

The AR systems are associated and implemented in different devices, such as personal computers, head mounted devices, smartphones, tablets and so forth. In fact, AR is a combination of several hardware and software technologies that work together to bring digital information in the visual field.

The recent innovation in mobile technology and wireless networking, allowed the development and improvement of mobile AR. It represents a useful system which allows users to receive and interact with augmented information everywhere, which otherwise would not be available without a stationary position (Höllner and Feiner, 2004).

Nowadays, mobile AR is mainly based on smartphones (hand-held devices) but might be replaced by smart glasses (SG), which are hands-free systems and might have great potential to become the main platform for AR (Lee and Hui, 2018).

SG are head-worn miniature computers, provided by a display in front of the user's eyes, representing the main discriminating feature. The augmented overlay contents can be shown on the display with three different optics systems—video, optical and retinal see-

through. The first one combines the real and virtual view in one completely digital user's vision, the second one overlays the virtual objects straight to a real world user's vision and the last one, with low-power laser light, projects the virtual objects directly onto the retina. Smart glasses are also commonly provided with a camera for image acquisition, sensors (GPS, accelerometer, gyroscope, etc.) and input controls (gesture, voice) (Syberfeldt et al., 2017).

AR systems are applied in many different areas mainly in education, manufacturing, medicine, tourism and entertainment (Yuen et al., 2011; Billingham et al., 2015; Holata et al., 2018; Fan et al., 2018; Bottani and Vignali, 2019; Zhang et al., 2019; Cejka et al., 2019). There is an increasing interest in this matter attested by the continuously growing number of research articles and conference papers published on AR so far. As shown by the bibliographic data analysis in the Scopus database, the published documents increased from one hundred in 1997 to over three thousand in 2018.

In the agricultural sector, one of the first research works on AR applications was published by King et al. (2005) concerning the development of an AR system to provide information on the grape field. Other authors investigated the importance of the AR technology in agriculture, focusing on fertilizing and spraying operations (Santana-Fernández et al., 2015), weed identification (Vidal and Vidal, 2010), greenhouse management (De Castro and Cardoso, 2013) and farmer management support (Liu et al., 2013; Katsaros et al., 2017). Additionally, Cupial (2011) underlined the importance and the great potential of AR in the agricultural field. However, only a few of these studies are focused on wearable AR systems and its potentiality to support and improve farmer activities (Okayama and Miyawaki, 2013; Santana-Fernández et al., 2015; Huuskonen and Oksanen, 2018). Furthermore, no research is still carried out on the application of smart glasses for AR in the livestock sector, especially in the growing field of the technologies used in Precision Livestock Farming (PLF).

Smart glasses might represent an important instrument, complementary to other tools used in PLF, to make available substantial information to farmers in real time. In fact, augmented reality will soon become popular, especially since there are many areas in which its implementation will be advisable (Cupial, 2011). Recent studies have

underlined how the implementation of precision technologies in livestock farms improved animal welfare and management (Fournel et al., 2017; King et al., 2018; Caria et al., 2019; Halachmi et al., 2019), farm profits and environmental sustainability (Caria et al., 2013; Todde et al., 2017; Tullo et al., 2019). Likewise, Todde et al. (2016) showed a positive association among technological investments and a farm's energy efficiency.

Smart glasses for AR are closely related to PLF principles (Wathes et al., 2008) since they could help farmers to manage the animal husbandry precisely. These technologies might easily provide useful information on the individual head about its identification, health status, productivity, feed ration and so forth.

Another important aspect regarding the use of SG in agriculture is related to farmer operations, which requires the use of both hands. Therefore, using a hands-free system information on plants, animals and soil can be obtained while working (Okayama and Miyawaki 2013).

The aim of this study was to evaluate the performances of an augmented reality head-wearable device as a valuable and integrative tool in precision livestock farming. The research questions to be answered by this study were: (i) which are the possible applications of the smart glasses in livestock farming; (ii) which could be the smart glasses utility in the farm management considering the available functions; (iii) how do the smart glasses perform during on-farm operations.

2. Materials and Methods

In this study, the GlassUp F4 Smart Glasses (F4SG), produced by an Italian company (GlassUp, Modena, Italy) were adopted. F4SG are AR viewers (Figure 1), mainly designed for industrial use, that work in pairs with a remote-control Dashboard (management software to be installed in computers).



Figure 1. GlussUp F4 smart glasses adopted in this study: (1) joypad; (2) video/photo camera; (3) front light; (4) smart glasses right side button; (5) audio jack 3.5; (6) combiner to visualize the augmented contents; (7) frontal protection lens.

The F4SGs are coupled with an external joypad, which allows accommodation of the battery pack and control of the glasses with navigation buttons (enter, clear and arrows up, down, right, left) and five function keys that can be set with different tasks (front light, photo capture, video recording and scan-code). In one side of the joypad there are a series of led indicating the battery state of charge (4 blue and one red), the Wi-Fi connection and the Bluetooth status (connected or not connected). Furthermore, on the right side of the glasses, there is another button that can be set with one of the commands listed above. The external joypad contains the Wi-Fi system that was used to connect the smart glasses to the phone and to internet. In Table 1, the main features of the tested smart glasses are reported.

Table 1. Features of GlassUp F4 Smart Glasses.

Item	Technical Features
Processor	Cortex A9
Flash memory	8 Gigabytes
Operating System on board	Linux
Display	Color filter Active Matrix LCD (on right eye) Full color 640 x 480 pixel (VGA)
Sensors	Accelerometer (9 axis), gyroscope, compass, temperature and lux sensors
Connectivity	WiFi, Bluetooth
Camera	Full Color, 5 Mpixels, 15 FPS
Battery	Li-Polymer 5000 mAh
Operating temperature	5–35 °C
Weight (glasses)	251 g
International Protection (IP)	31

During the study, some F4SG functions, such as QR (Quick Response) code scanning, VoIP (voice over internet protocol) call and video streaming, were tested in the laboratory and in a real work environment to investigate the possible applications of the smart glasses in the agricultural field and specifically in livestock farms.

2.1. Laboratory Tests

Several tests were performed in the laboratory of the Department of Agricultural Science at the University of Sassari, to assess the implementation of smart glasses for AR in livestock farming. The performance of QR code scanning function was evaluated. The trials were carried out simulating the main activities accomplished in livestock farms (milking, feeding, breeding, etc.). The on farm information used in these tests were incorporated on QR codes. The QR code, generally organized as black squares arranged in a square grid on a white background, holds a wide storage capacity enabling the encoding of many different types of information (Denso Wave, 2019). This type of code

has a high correction rate, meaning that the QR code can be read correctly even if a quota of the symbol is tainted or torn (Furht, 2011; Denso Wave, 2019). These features make the QR code suitable for application in agricultural contexts.

2.1.1. QR Code Scanning Time

The QR code scanning time and battery life were tested in continuous and in repeated measurements. The QR code scanning time, considered as the time frame from activation of the scan-code function to the visualization of the associated file, was monitored. The scan-code function was associated with the right-side button of smart glasses. The trials consist of a continuous QR code scanning and file opening until the battery was completely discharged. For this test, 24 QR codes of three different sizes were printed with the following dimensions—3.5 cm (series 1), 4 cm (series 2), 7.5 cm (series 3) and with 25 modules per side. The series was placed on a vertical plane at 33 cm of distance between each single QR code and at a height of 160 cm, simulating position and height of the animals during milking operation. The QR codes scans were carried out by three different operators (named a, b and c) at a scanning distance of about 40 cm. The test was repeated for three times and the battery was completely recharged before the beginning of each test. The total number of QR codes scanned were 3489. The scanning time was monitored with a chronometer, which was started as soon as the operator activated the scan-code function on F4SG and stopped when the file opened up (Figure 2).



Figure 2. Laboratory tests: Quick response (QR) codes scanning procedure with a 7.5 cm code size.

2.1.2. QR Code Scanning Distance

An evaluation on the QR code size in relation to optimal and maximum scanning distance was carried out. The optimal scanning distance refers to the distance at which the operator is able to scan and open the file immediately, while the maximum one is the distance beyond which the QR code is not detected by the smart glasses camera. Six QR codes of different dimensions were used— 1.5×1.5 cm, 3.5×3.5 cm, 4×4 cm, 7.5×7.5 cm, 13×13 cm and 20×20 cm all of these with 25 modules per side. The measured distance was between the vertical plane, on which the QR code is located (160 cm height) and F4SG camera. Furthermore, a linear regression between QR size and scanning distance was assessed.

2.1.3. QR Code and Farm Information Sheet

A Microsoft Word file was adopted to develop the Farm Information Sheet (FIS), which contained the information about the animals (breed, animal ID, group, lactation days etc.) and feed stocks (feed type, amount, quality, harvesting time, etc.) available at the farm level. A large amount of information can be reported for these issues, making the FIS hard to retrieve at a glance. For this reason, based on farmers' suggestions, we

selected the most important information that should be available to the farmers on the SG. These records were outlined on a single page to allow the user to visualize immediately all the information without using the joypad. The FIS was written in Time New Roman with a font size of 18 points. Moreover, a milk emission flow curve was included in the FIS and uploaded, as a pdf file, in the F4SG memory. Each FIS was associated with a unique QR code.

Using the scan-code function of the F4SG (activated using the key on the right side of the glasses) the user is able to scan, open and visualize the FIS on the smart glasses display.

2.2. Audio-Video Quality Tests

2.2.1. Video Call Lag Time

The lag time of a remote video call between F4SG and laptop (dashboard) was evaluated (Figure 3). The test was carried out with the emitting operator (EO) wearing the smart glasses (placed in the livestock farm) and the receiving operator (RO) that was the person using the laptop (placed in the lab of the Department of Sassari). Smart glasses and laptop were connected using 4G mobile phone (Huawei P20 lite) network internet tethering. The audio-video lag time between the EO and RO was evaluated by synchronizing the operators' clocks and recording the emission and receiving time of a predetermined signal for audio and a predetermined position for video (Muensterer et al., 2014). The lag time test was carried out with two different streaming qualities, 4G and 3G and for each quality and types of signal (audio or video) were recorded 16 times both for EO and RO.



Figure 3. While working usage of the smart glasses hands-free device in the paddock.

2.2.2. Vision Testing Through F4 Smart Glasses Via Remote Internet Connection

A vision quality test was carried out to evaluate the quality of the transmitted image through the F4SG. A standard Snellen vision test charts were performed. The test was achieved with two different streaming qualities (3G and 4G). The EO was placed at 50 cm distance from the Snellen chart (Muensterer et al., 2014) and the RO read the characters in the 16-inch laptop monitor.

2.3. Battery Life

During the QR code scanning and video call, tests also monitored the battery life. In the first case, checking its status at the end of each scanning series (24 QR codes), and in the second one checking the status during a continuous VoIP call, monitoring the battery LED on the side of the joypad.

2.4. Farm Tests

The F4SG were utilized in a dairy sheep farm in Sassari (Sardinia, Italy). The audio-video quality of the transmitted contents from the smart glasses to the Dashboard was

evaluated. In fact, the background noise and different level of light exposure, in real work environments, may affect the audio-video comprehension and the QR code readability.

The tests were carried out with the RO that was located in the lab of the Department and the EO which was transmitting from the sheep shed and milking parlour. For this test 3G streaming quality was used. Furthermore, the scan-code function was tested with the QR code positioned, respectively, on bale silage and on the sheep's tail. This enabled to provide information in real time on the features and composition of the feed (type of forage, humidity, harvesting data, etc.) and for the individual animal. Two 28 × 28 cm QR codes were attached to the bales silage, placed at 200 and 90 cm height and scanned from 3.0 to 5.0 m distance from the ground and from the tractor cabin (Figure 4). On the sheep's tail were attached 3.5, 4 and 7.5 cm QR codes, placed at 160 cm height and scanned from 50 cm distance.



Figure 4. On-farm QR code scanning procedure tests. The operator with smart glasses was placed at different distances, heights and positions in the tractor cabin while selecting the appropriate bale silage for feed preparation.

2.5. Statistical Analysis

Descriptive statistics (arithmetic average, standard deviation, minimum and maximum) were calculated for the scanning time in relation to the QR code size and operators. The variations in the parameters were also analyzed by evaluating frequency distributions. Statistical analysis was carried out by comparing the scanning time within different QR codes size (3.5 cm, 4 cm, 7.5 cm) and within three operators (a, b, c), using the Mann-Whitney U test from the R Studio software (version: 3.4.4).

3. Results

The study showed results for commercial smart-glasses GlassUp F4, which were stressed to determine their performance in extreme conditions and evaluated for possible applications in livestock farming operations.

3.1. QR Code Scanning Time

The purpose of this trial was to estimate the opening times linked to the use of the QR scanning function. The importance of this test is underlined by the fact that preliminary evaluations can help understanding of which agricultural and livestock activities this new technology can be integrated with.

The results obtained during the scanning of three different QR code dimensions are shown in Table 2. In all cases there is a wide range between minimum and maximum scanning time (30.6, 29.7 and 24.4). The size of the QR codes significantly influenced the scanning time ($P < 0.001$) regardless of the distance of the operator. Specifically, the F4SG had minor response time when scanning QR codes with 7.5 cm size (7.7 s), rather than other small dimensions, 8.6 and 11.0 seconds respectively for 4.0 and 3.5 cm. The difference between the smaller and the bigger codes was, on average, 3.3 seconds. This time was negatively perceived by the participants, even if in real work conditions 3 seconds may not affect the working time.

Table 2. Average scanning time (ST) and standard deviation (SD) with regard to QR code size. Minimum and maximum average scanning time for each QR size are reported.

QR Code Size (cm)	ST (s)	SD	Min ST (s)	Max ST (s)	Tot. scan (N°)
3.5	11.0 ^a	5.7	4.1	34.7	1143
4.0	8.6 ^b	3.8	4.2	33.9	1194
7.5	7.7 ^c	2.8	3.9	28.3	1152

Values in the same column with diverse superscript letters are statistically different ($P < 0.001$).

Table 3. Average scanning time (ST) and standard deviation (SD) per operator. The minimum and maximum average scanning time for each operator are reported.

Operator	ST (s)	SD	Min ST (s)	Max ST (s)
a	9.4 ^a	5.0	4.3	34.7
b	8.7 ^b	4.1	3.9	33.2
c	9.1 ^a	4.1	4.1	33.6

Values in the same column with diverse superscript letters are statistically different ($P < 0.001$).

The results related to the operators' performance are summarized in Table 3. QR code scanning time was significantly different between operators "a" and "b" and between "b" and "c." There are no differences between operators with higher average values. All operators had, on average, comparable minimum and maximum values of scanning time (about 4.1 s and 33.8 respectively).

There is a wide distribution in QR code scanning time frequency. In 67% of cases, the scanning time was between 5.1 seconds and 9 seconds (Figure 5). Only 3 % of the scanned codes occurred after 5 s or less, while 5% took more than 19 s. The maximum time recorded during the tests corresponded to 34.7 seconds and although smart glasses enabled hands-free working, excessive response time of scanning procedures significantly increase the operating time.

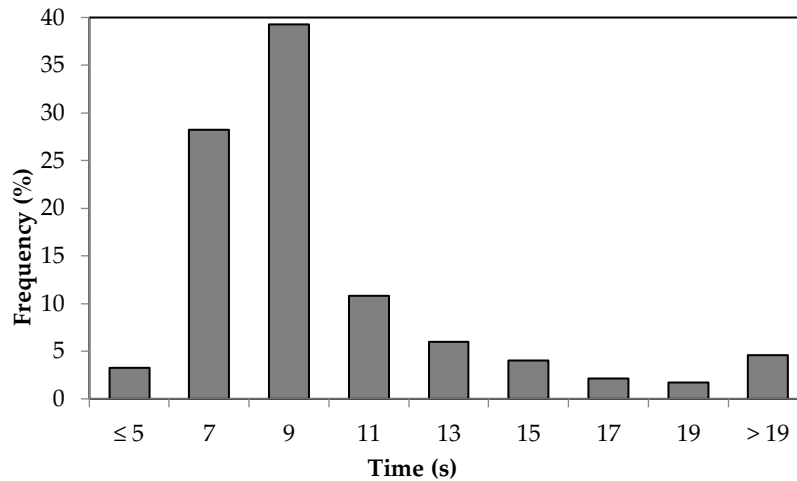


Figure 5. Frequency distribution diagram of QR codes scanning times.

3.2. QR Code Scanning Distance

Using QR codes in livestock farming may meet two main limitations related to their size and the scanning distance. In fact, the surface available for supporting QR code may be limited (i.e., animal body) and similarly, the reading distance of QR codes could be strictly linked to the farm activities (i.e., selecting the feed from the tractor cabin).

The correlations among measured scanning distance and QR code dimensions are shown in Figure 6. The results highlighted that the optimal and the maximum scanning distances are linearly correlated with the code size. There was a high relationship between maximum ($R^2 = 0.997$) and optimal ($R^2 = 0.995$) scanning distance with the QR code size. The optimal distance resulted in ten times the QR code size and thirteen times the maximum one. Likewise, other authors (Qian et al., 2017) confirmed that the QR code readability was affected by the interaction of scanning distance and code size. Bigger QR code size allows more scanning points than the smaller one. Moreover, the readability of QR codes with standard print resolution features (4×4 pixels per module with 300 dots per inch) is possible with common optical devices (Qian et al., 2017).

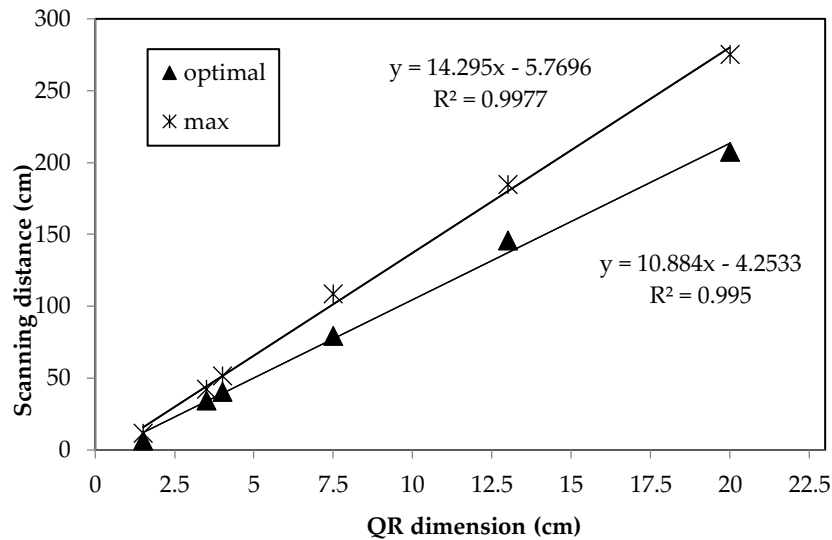


Figure 6. Correlation between QR code size and scanning distance, optimal (▲) and maximum (×).

The results obtained during the feeding procedures at the farm, while working from the ground or with the tractor, showed that a distance higher than about 4.0 m did not allow retrieval of the information on smart glasses (Figure 7). Nevertheless, 3.0 m distance from the QR code to the device enabled a prompt response.



Figure 7. Farm scanning test to detect feed information sheet on the bale silage. The QR code of 28 × 28 cm size placed at 90 and 200 cm height.

3.3. Battery Life

Battery drain while working can be a serious issue to deal with. Likewise, knowing the amount of information achievable in terms of the amount of scanning by means of smart glasses will optimize the work process. In order to qualify the battery life of the F4 glasses, two tests were performed considering different operative applications. The results of the battery life are listed in Table 4.

Table 4. Battery life and smart glasses function used (mean of three repetitions).

	Battery Life (h)					Total Battery Life
	Level 4	Level 3	Level 2	Level 1	Level 0	
Scan-code	1.11 ± 0.41	1.89 ± 0.26	1.02 ± 0.45	0.98 ± 0.32	1.86 ± 1.12	6.87 ± 0.42
Video call	1.45 ± 0.33	2.13 ± 0.42	1.26 ± 0.29	1.33 ± 0.31	0.83 ± 0.58	7.01 ± 0.33

3.4. Audio-Video Quality

The audio-video lag time was calculated with two different streaming qualities (3G and 4G). In both cases, a lag time was registered between the emitting and receiving signal. The video lag time was 2.13 and 2.28 seconds, respectively for 3G and 4G. Instead, the audio lag time was lower (0.67 s) for the 4G than the 3G streaming quality (1.81 s). Setting the 4G streaming quality in F4SG allowed the receiving operator to improve the reading performance of the Snellen chart video-transmitted (Figure 8). In fact, with the 4G streaming quality, all characters 4 mm height or larger were correctly identified, while reading the line 3 mm an average of 55.5% of letters were recognized. The 3G streaming quality allowed us to correctly read (100% of the cases) the 7 mm characters' height or larger, while 6 and 5 mm height were legible in the 55.9 and 6.5% of the trials, respectively. The character height 2 mm or smaller was illegible in all of the trials.

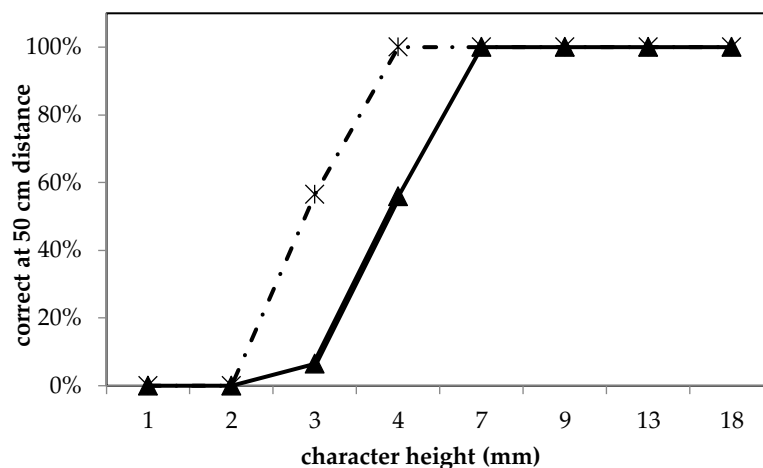


Figure 8. Snellen chart vision test, describing the percentage of correct letter individuation in relation to its dimension. The two streaming video qualities are reported 3G (continuous line) and 4G (dashed line). The test was performed through F4 smart glasses at 50 cm distance from the chart. Reading was carried out on a 16 inches display.

The outcomes related to the video performance carried out during the farm tests underlined the high quality necessary to document all the on-farm related circumstances. Difficult lighting conditions may compromise the video quality. However, during the trials conducted on milking parlour, that is, in a low lighting environment, did not affect the device and operator performances (Figure 9).



Figure 9. Testing remote assistance smart glasses' performances during mammary gland inspection.

The audio quality of F4SG was performed at different intensity levels of background noise at the farm. One of the most critical circumstances was found while driving a tractor, followed by working in the sheep shed and during milking. However, the conversations between the emitting and receiving operators were fluent and without misunderstandings. Specifically, emitting and receiving operators did not have any difficulties hearing every sentence while speaking at normal volume.

4. Discussion

The study provided results of the use of commercial smart glasses GlassUp F4, which were stressed to determine their performances in extreme conditions and evaluated for possible applications in livestock farming operations. In agricultural and livestock tasks, specific information per subject is commonly needed (e.g., animal, plant, orchard row, field, greenhouse, etc.). Using F4SG to retrieve information in several on-farm activities, which were previously loaded (as a file) onto the memory of the device. One or more pages of information can be visualized, scrolling through different pages using manual control, as there is no verbal scrolling command pre-programmed into the current version of SG. However, the use of manual commands instead of vocal commands seems to be the optimal solution, due to the presence of background noises in many different farming contexts (Zaninelli, 2017).

The subjects must have an identification code (i.e., QR code) to be detected by the operator. The trials on the scan of QR codes with different dimensions at the same position were effectuated to underline the importance of it on the scan operative time. It is important to accurately choose the size of QR code, especially when the scanning occurs on animals standing in self-locking yokes, in milking parlours or in cattle sheds (Figure 10). In fact, as found in this study, scanning time with SG was inversely proportional to QR code size. The distance of the QR code is fundamental to optimize the scanning process in terms of time and operator comfort (Ferreira et al., 2016; Qian et al., 2017).



Figure 10. Scanning QR codes positioned on the sheep's tail in self-locking yokes at the milking parlour.

The influence of the operator while using smart glasses was clear; significant differences among the three average scanning times were observed in this study. Several works explained the different aptitude and acceptance of users for modern technologies (Obeidyet al., 2017; Rese et al., 2017; Wild et al., 2017; Jacobs et al., 2019; Manis et al., 2019), which probably affected the scanning times of this study.

The response time found among the three QR code series did not appear considerable because the operator could continue to work since the information is visualized hands-free on a head-worn display. For this reason, the response time should not be considered dead-time. In fact, scanning time may seem long but we have to consider that into this time frame several steps are coupled, specifically, scan-code function activation, QR code scanning, file opening and file visualization. The only step that needs the attention of the operator is related to the QR code scanning. During the other steps, the operator is able to accomplish the tasks without staring at the combiner (SG display). Moreover, watching the optical display of smart glasses is not comparable to looking at a monitor. In fact, the information is projected into a lens positioned few centimeters from the user's eye. This allows the user to see through the document displayed, thanks to the human ability to focus on objects at different distances.

In recent years, technology progress has accustomed users to faster connections and rhythms. As a consequence, the response time observed in this study may be negatively perceived by the operator when using SG for the first time.

The quality of the camera appears quite good during the video call or video recording. However, indoor and outdoor lighting may affect the readability on smart glasses, as observed during on farm investigations. The same considerations can be made for photo capture in different locations. Furthermore, the front light positioned above the field of view allowed improvement of video and photo quality in a low lighting environment (dark places). The lag-time during video-calls was steady over time, which allowed the comfortable use of this function for a long period and while moving to different working places. Specifically, using smart glasses for remote assistance may support unskilled operators during on farm activities, such as milking machine inspections (Figure 11).

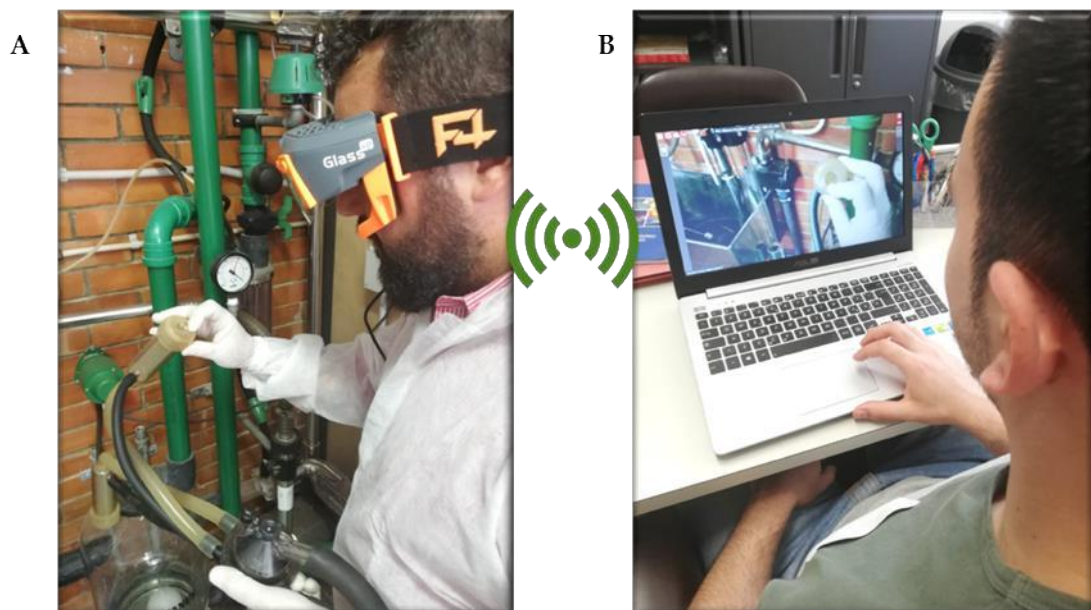


Figure 11. Remote assistance during milking machine inspection. (A) The emitting operator is inspecting the milking machine components, wearing augmented reality viewers, while working hands-free. (B) The receiving operator is assisting in real time to the emitting operator while working remotely.

The inconvenience of having an external joystick connected with a cable to the SG was balanced by the long battery life. In fact, the results demonstrate the F4SG works on an average of 7 h without any battery charge, both when scanning and video-calling. Most of the farmers work more than 8 h per day but SG for AR would barely be used, uninterrupted, all day. Therefore, the long battery life of this technology offers multiple applications in the agricultural and livestock field, ranging from remote assistance (video-call) to precision agriculture (QR code scan). Muensterer et al., 2014 tested the battery life of a head wearable device in different conditions, obtaining between 8.5 and 12 h of activity on a typical clinical day, while in continuous video recording or videoconferencing the battery lasted about 30–40 min. Additionally, a systematic review conducted by Yoon et al., 2017, on AR application for the surgeon, highlighted the disadvantage of the limited battery life of commercial head-up displays. In fact, among the seven wearable devices involved, three of those held a battery life up to 2 h and only one had a battery life ranging from 2 to 12 h.

Overall, using the available functions of F4SG (Table 5) enabled the operators to accomplish the typical on-farm activities involved in this study. In fact, the smart glasses for augmented reality have proven to be a valuable and integrative tool in accordance with precision livestock farming principles.

In this study, we explored the potential role that smart glasses for augmented reality (GlassUp F4) might have in agricultural and livestock farming. The F4SG are currently available on the market as AR goggles primarily designed for industrial applications. However, the outcomes of our study demonstrate that AR viewers may provide excellent opportunities in agriculture. The QR code scan function resulted in a helpful tool to support the breeders in flock management and also in feed procedures. The clear and fast readability of the information related to the single subject (e.g., animals and feed stocks), combined with the large number of readings that SG performed, allowed F4SG adoption even on large farms. In addition, the 7 h of battery life and good quality of audio-video features highlighted their valuable attitude in remote assistance, supporting farmers in the field. Many advantages can be offered to farmers from AR viewers, enabling real time file consulting, data collection, data sharing and remote assistance, all done while working

hands-free. These are just some of the application of the smart glasses for AR in the precision livestock farming context. Nevertheless, some limitations have been found, in fact, there were no software applications during the study interval, specifically developed for the livestock sector. We are looking forward to evaluating competitor devices and providing feedback to support the forthcoming development of smart glasses designed for agricultural purposes.

Table 5. Potential applications of smart glasses F4 in the livestock sector.

Smart Glasses F4 Functions	Applications	Examples
QR code scanning	Single subject identification	In livestock farms could help farmers to identify the animals and its productive data. Identify feedstock composition to improve feeding strategies. Retrieve fleet equipment information about history, maintenance, activity, etc.
VoIP call	Hands-free calling	The farmers could make hands-free calling while working, providing and/or receiving business and operative information on-the-go
Video streaming	Remote assistance while working	The farmer could share his point of view (live sharing) with a technician in real-time during maintenance procedures of equipment (e.g., milking parlor inspections)
Image acquisition	Photo capture and editing	During animal selection, farmers can take picture through the smart glasses to save the animal phenotypic relevant features. Photo acquisition may be also useful to underline the characteristics of spare parts of farm's equipment. Photos may also be edited from the dashboard
Video-Audio recording	Video acquisition and saving	Recording and saving video off-line about different situations as system decision support tool; from animal diseases' symptoms to systems' anomalies.
Audio recording	Save notes and memorandum	The tractor driver could record voice annotation about on-farm procedures and draft by voice a checklist, while solving field operations.

File consulting	Audio, video, photo and text accessing during farm activities	Hands-free and immediate access to animal information (productions, health status, identification number, etc.). Tractor’s handbook consulting for maintenance support. This function allows to follow the on-screen instruction for problem solving or to recall and rapidly visualize the needed information.
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5. Conclusions

The first evaluation aimed to discharge the battery during continuous scan-code function utilization, where the number of documents opened ranged from 860 to 1411. The second test was performed to evaluate the battery life during a video-call, assuming the use of smart-glasses for remote assistance or to have a visualization of the user’s point of view while working. The battery charge lasted, in both tests, for about 7 h. The battery life in each of five levels indicated by an LED on the joypad was variable and did not follow any definite trend both in the scan-code and the video call tests. The results showed that the only “level-0” in scan-code function lasted more than its equivalent video-call test (+55.4%) and the longer time was recorded in “level-3” for both cases. Knowing the duration time for each battery level, indicated by the LED, may be useful whether SGs are used occasionally, without necessarily having to be recharged. In fact, intensive use (more than 7 h) of SG may be rarely practiced in livestock farms.

Author Contributions: M.C., G.S. and G.T. conceived and designed the experiments, wrote the manuscript and analyzed the data. G.S. and M.P. collected the data. M.C., G.T. and A.P. revised the manuscript. All authors read and approved the final manuscript.

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CHAPTER 3

Assessment of Video See-Through Smart Glasses for Augmented Reality to Support Technicians during Milking Machine Maintenance

This manuscript is ready for submission to a scientific journal

Abstract

Smart glasses (SG) for augmented reality (AR) are an emerging digital technology under investigation in the agricultural sector. The AR potentialities were underlined, in some scientific contribution, as a support tool for farmers' activities and for the decision-making process. One of the most practical applications studied for AR was in the maintenance operations, where the use of SG showed high capability. This work focuses on the evaluation of the performances and applicability of an SG with a video see-through display system, testing the device's available functions in the agricultural frameworks. In addition, an AR assistance scenario for the milking machine inspection was developed, describing the main steps involved in the functioning of the maintenance operation through SG. In the study, the Vuzix M400 SG were used. The tests evaluated the audio-video quality, the battery life, the detection capabilities of AR markers, and, finally, the voice control interaction system. The results showed the capabilities of SG to reach the AR information from a long distance (through QR code scanning) in a short time interval and to transmit audio and video with a high level of detail allowing discriminate small objects during remote assistance with reduced delay. Moreover, the tests allowed to underline that this device can be managed completely hands-free with the voice control function but only in situations with a maximum noise level of 70-75 dB. The built maintenance scenario represents an example of an AR remote assistance application in the agricultural context. The purposed maintenance scenario underlines the potential that the AR could have in the agricultural sector to assist and guide both farmers and technicians. The proposed scenario underline how through SG could be used to solve problems while working on simultaneously visualizing the information having hands free to proceed with the maintenance. More complex, but not complicated, applications or assistance scenarios should be developed considering the farmers' needs, also taking into account the implementation of the cloud computing services.

Keywords: Augmented Reality; Precision Agriculture; Precision Livestock Farming; Smart Technology Performance; Machine Maintenance

1. Introduction

Over the last few years, we hear speaking about smart farming, precision agriculture, precision livestock farming, and recently about agriculture 4.0 (Banhazi et al., 2012; Rose and Chlivers, 2018; Klerkx et al., 2019). All these terms have been related to different and even complex technologies, and to information, digital and robotic technologies, that more and more have been studied and will be used in the agricultural sector. The main objectives of introducing this type of technologies are to improve the farms' productions as the crop or livestock yield, streamline the input use (fertilizer, pesticides, etc.) and reduce waste during the whole production process, bringing to more sustainable agriculture (Wolfert et al., 2017; Saiz-Rubio and Rovira-Más, 2020; Bolfe et al., 2020). Hence, the spreading of digital technologies could bring in the agricultural and livestock farming sector economic, social, and environmental benefits, in relation to internet access, representing the most critical factor for digital technologies diffusion (Tullo et al., 2019; Trendov et al., 2019). A lot of new smart technologies have been studied and used to support and simplify the farmers' work such as auto-guidance equipment, variable rate technology, or automatic milking systems.

The smart glasses (SG) for augmented reality (AR) are a digital technology under investigation in the agricultural sector, where the potential applications were underlined, as a support tool for the farmers' activities and the decision-making process (Huuskonen and Oksanen 2018; Caria et al., 2019; Caria et al., 2020). Furthermore, the popularity of AR technologies will grow in the next years thanks to the improvement and evolution of cloud computing technologies that will strengthen the power of AR experiences (Munoz-Saavedra et al., 2020). Possible applications of AR have been in the maintenance (Palmarini et al., 2018) or manufacturing field (Baroroh et al., 2020) where AR showed high potential to enhance the operator performance. The AR overlaid 3D information may replace the paper-based or 2D digital instructions, also in the assembly/disassembly industrial sector where the use of AR technology was observed to require less time and workload to the assembly operators (Chu and Ko, 2021) reducing the error rate (Lai et al., 2020). The SG have been defined as a wearable computer, despite the lower computational power, designed to provide AR experiences through specific applications

and visualization systems where the virtual or digital contents are projected (Kumar et al., 2018). The central concept of AR systems concerns overlaying computer-generated contents in the real environment, hence augmenting the physical object with digital information (Milgram and Kishino, 1994). The SG technologies for AR could be currently considered as an emerging technology, even more in the agricultural sector, for which there are no customized solutions. In addition, the AR contents authoring is the main obstacle to the AR spreading, since the AR contents creation “requires high effort” and cannot be done “by shop-floor employees” (Quint et al., 2017). The SG can be distinguished concerning its features, principally for the AR elements visualization system (optical see-through, video see-through, and retinal display), the available interaction method (specific button and touchpad placed on the device, external joypad, voice control), and the tracking module integrated into the AR device as well as other characteristics (operating system, processor, functionality, battery life, framework design, etc.) (Syberfeldt et al., 2017; Lee and Hui 2018; Hamacher et al., 2019).

The tracking module is considered the central system of the AR technology allowing to the identification of the user, device, and environment positions and orientation and to anchor the virtual contents on the physical objects, and then to render combined digital and real elements on the AR device display (Siltanen, 2012). The tracking system can be supported by different sensors (accelerometer, magnetometer, gyroscope, video camera, RFID, GPS, etc.) in relation to which it is possible to distinguish the technique used by the AR device in vision-based or sensor-based methods. The former case concerns the use of markers (Template, DataMatrix, QR Code) or feature of the environment, in contrast with the other one that use inertial, magnetic, electromagnetic, or ultrasonic sensors to measure and pose the information (Palmarini et al., 2018). Despite the sensor-based methods have been considered fast and robust, marker-based tracking modules were preferred when a high accuracy during position estimation is required, e.g., medical sector (Daponte et al., 2014). This remains true until the precision and accuracy of the GPS receiver of the SG will be improved for a better AR content positioning especially for outdoor applications (Huuskonen and Oksanen, 2018). Moreover, the use of QR code-based technique were in-depth studied and applied to AR and SG case study,

representing one of the easiest methods to detect and overly augmented information (Siltanen 2012; Syberfeldt et al., 2017; Lee and Hui 2018).

One of the most practical applications studied for AR was in the maintenance operation, where the use of SG for AR showed high potentiality (Palmarini et al., 2018). In the agricultural sector, the maintenance operations of the machines have been a high impact on the farm's management costs, both in terms of time and economical resources, that tend to increase with the machine's hours of use and with the increasing of machines fleet (Minteh et al., 2019; Myalo et al., 2021). Using AR and SG technologies could improve farmers' performances and reduce costs for machines maintenance also receiving remote assistance from a technician on to go, even though as each new technology, AR and SG have them set of problems and challenges (Schlueter, 2018). In addition, the complex pandemic situation caused by the SARS-CoV-2 Virus is posing new challenges to assist in the field. In this context, guided or remote assistance supported by the SG for AR could play a strategic role in enabling workers to solve problems that arise especially with the machines to assure their regular maintenance.

The main features of the SG (visualization system, interaction system, and tracking method) could influence the user experience and farmer performance using the AR device while working. For this reason, it is important to evaluate and outline the differences among how different SG devices could perform in an agricultural context.

Hence, considering the features that characterized the SG, especially the visualization system that represents one of the main discriminating characteristics, and that previous study on the use of SG in agriculture focused on a specific device with an optical display system (Caria et al., 2019), this work focuses on the study and evaluation of the performances and applicability of an SG with video see-through system, testing the available functions for the agricultural frameworks. Moreover, considering the future employment of SG for AR in the maintenance of the agricultural machines to assist farmers on the field, an AR assistance scenario for the milking machine inspection was developed, describing the main steps involved in the functioning of the maintenance operation through SG.

2. Materials and Methods

In this study, the Vuzix® M400 Smart Glasses (M400), produced by the Vuzix Corporation (25 Hendrix Road West Henrietta, NY 14586, USA) were adopted. The M400 is an AR viewer designed for the hard workplace, composed of three main components: smart viewer, power bank, and mounting frame. The optical system of the M400 is a video see-through display and on the side of the smart viewer, there is the navigation system that allows interaction with the user interface. There are two types of tangible navigation systems, the classical one, composed of three keys (up, down, enter) and then the touchpad. In addition, there is another navigation system controlled by the voice that allows interacting with the M400 with a preregistered voice command. The power bank is equipped with three led indicating the status of the battery. In Table 1, the technical specifications of the SG used are stated.

Table 1. Main technical specifications of Vuzix M400 Smart Glasses (as reported by the company)

Item	Technical Features
Processor	8 Core 2.52 Ghz Qualcomm XR1
Flash memory	64 GBytes
Operating System (OS)	Android 8.1
Display	Occluded OLED, 24-bit color, 640x360
Field of view	16.8 degrees (5 inches)
Sensors	Gyroscope-accelerometer-magnetometer (3 axis)
Connectivity	GPS, Wi-Fi, Bluetooth, USB
Camera	12.8 Megapixel, 30 fps
Battery	Lithium polymer 1000 mAh (power bank)
Battery life	2 - 12 h
Controller input	Touchpad, 3 buttons, voice command

The tests were performed in the laboratory of the Agricultural Sciences Department of the University of Sassari. The first trial involved the device's performance evaluation

using the available functionalities and applications. Specifically, the tests evaluated: the audio-video quality transmitted and received from the M400, the battery life, the detection of AR markers (QR codes), and, finally, the voice control interaction system. Moreover, a milking machine maintenance framework was built, through a specific application, to support technicians and farmers during maintenance procedures.

2.1. QR Codes Tests

The scanner app was used to evaluate the performance of the M400 (time and distance) to detect markers that allow to merge the AR contents on the real. In this study, the QR code was used as marker thanks to its capability to store a great amount of information into it, generating up to 40 versions in relation to the encoded information (Denso Wave, 2021). For the trials, specific farm's data were encoded in two different QR codes versions. In the first QR code (Figure 1a) the URL linked to the farm information was encoded. This QR code was a Version 3 (V3) composed of 29 x 29 modules (black or white square in the QR code). In the second QR code (Figure 1b) the farm information was directly encoded in text format inside the code, resulting a Version 11 (V11) composed of 61 x 61 modules.

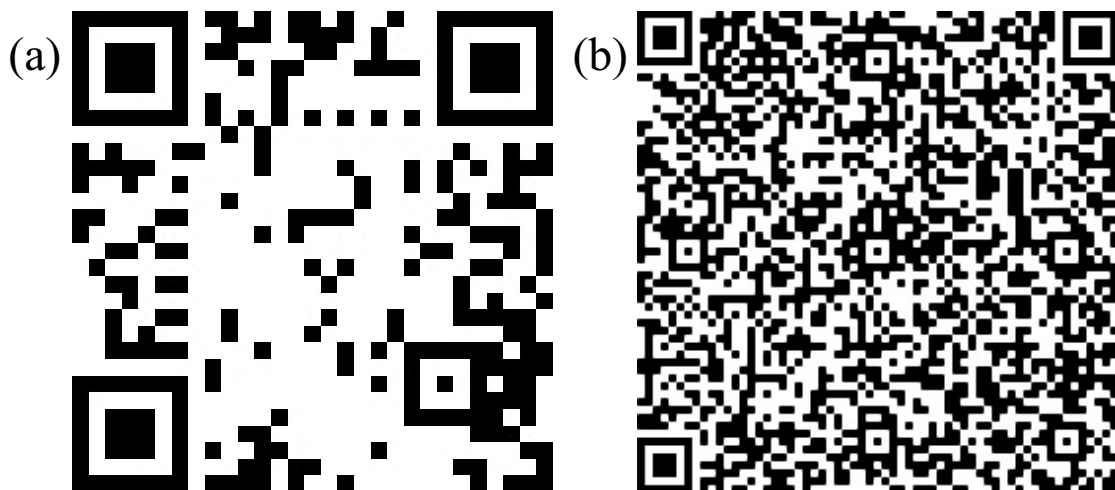


Figure 1. QR codes used during the trial: Version 3 (V3) with 25 modules (a); Version 11 (V11) with 61 modules (b).

Using both QR code versions (V3, V11) the minimum and maximum scanning distance were measured from the M400 camera. QR codes with increasing printed size, ranging from 1.5 cm per side to 20 cm per side, were adopted. In order to assess the required time to display the farm information on the SG (scanning time), three QR codes of different printed size (3.5 cm, 4 cm, 7.5 cm per side) were tested. The scanning time represents the time frame from the activation of the scanner app to the visualization of the associated information. The codes were placed on the wall, at wearers eye level and scanned at 40 cm. The scanning tests were performed until the end of the battery and repeated for two charging cycles, collecting a total of 2,254 records.

2.2. Audio-video quality transmission test

Two tests were performed in order to evaluate the audio-video quality contents from the SG to a remote device (PC) using a Voice over Internet protocol (VoIP) remote call. The first test concerns the lag time detection to assess the time needed to transmit audio-video between M400 and laptop. This trial was performed using two different applications: Vuzix® Remote Assist application (App1) and Brochesia® B View application (App2). Both Apps are free downloadable application to connect field workers, provided by a mobile device (smartphone, smart glasses), with a remote expert (web platform) for real-time audio/video cooperation. Moreover, to fully use both applications subscription is required after the trial version. The lag time of the video and the audio transmitted from the M400 to the laptop were registered synchronizing the clocks of the two operators and recording the emission and receiving time of a fixed signal for audio and a programmed position for video.

The second test, concern the evaluation of the observable level of detail of transmitted image through SG. It was performed using a standard Snellen chart placed at 50 cm from SG and displaying the characters on the laptop screen. Error rate was measured and related with the decreasing size of the characters (Muensterer et al., 2014).

The tests were carried out with two different video quality resolutions (VGA, 640x480 pixels; HD, 1280x720 pixels) and for each one the lag time were measured 20

times, whereas the Snellen chart test was performed by two operators. Lastly, during these trials the status of the battery in a continuous audio-video transmission was monitored.

2.3. Voice control test

The voice commands were tested to evaluate the noise levels, reachable in different agricultural contexts, that might influence the M400 to recognize voice inputs. The available speech commands were tested at growing levels of noise starting from 65 dB to 85 dB and in a silent environment (40-50 dB) as control. The list of speech commands consists of 39 programmed commands such as, “Hello Vuzix”, “Go back”, “Move/scroll down”, “Scroll left”, “Go up”, “Open”, “Select this”, etc. The test was performed by four operators and the sound pressure levels were monitored using Trotec SL4 (Trotec GmbH) class 2 sound level meter. During the tests, the voice commands were considered unrecognized after three failed repetitions with an increasing tone of voice.

2.4. Assistance scenario for the farmer

In this work was designed an assistance scenario through an AR application developed by Brochesia[®] (BStep). This software application allows building workflows to guide the operator during the maintenance activity with punctual augmented information using SG.

The assistance scenario considered was the measurement of pulsation characteristics related to the mechanical test from milking machines. These measurements commonly involve all the milking units of the milking machine. The workflow was developed according to the International Organization for Standardization (ISO) 6690:2007 and 3918:2007 standards, considering the dry test. The assistance procedures were associated to a QR code placed on the milking machine and available through the scanning function of the SG. The workflow for the milking machine inspection process was tested on the milking system in the laboratory of the Agricultural Sciences Department of the University of Sassari (Italy).

2.5. Statistical analysis

Descriptive statistics (arithmetic average, standard deviation, minimum and maximum values) were assessed and reported for the QR code, the lag time and the voice control tests. Statistical analysis was carried out performing a Kruskal-Wallis rank sum test for the scanning time and audio-video quality transmission data and a multiple comparison after Kruskal-Wallis test ($P < 0.05$). The analyses were performed with R Studio software (version: 4.0.5).

3. Results and Discussion

3.1. Performance and functionality tests

The markers e.g., QR code, bar code, etc., are important elements in AR systems because represent a valuable tracking method to overlay digital contents on physical and real objects. The capability of the AR device to detect the markers and the distance from which it is detectable, are aspects that allow to understand the accessibility of the digital information. For these reasons, the minimum and maximum scanning distance of different QR codes printed size, by using the M400, were evaluated. Figure 2 describes the results obtained from the scanning distance of the V3 (Figure 2a) and the V11 (Figure 2b) QR codes in relationship with their size. As expected, it was observed that the minimum and maximum scanning distances were directly proportional to the QR code size for both code types. The minimum distance and code dimension ratio for the two types of codes was constant (6.5 on average), as the minimum scanning distance was dictated to the camera framing. A different situation was observed for the maximum scanning distance of the two codes. In fact, the maximum scanning distance was higher for the V3 than the V11 code, with a distance and code dimension ratio of 48.8 and 21.5, respectively. Hence, using the M400, allowed to detect the augmented information from almost 2 meters scanning a QR code of 4x4 cm size with 29 modules.

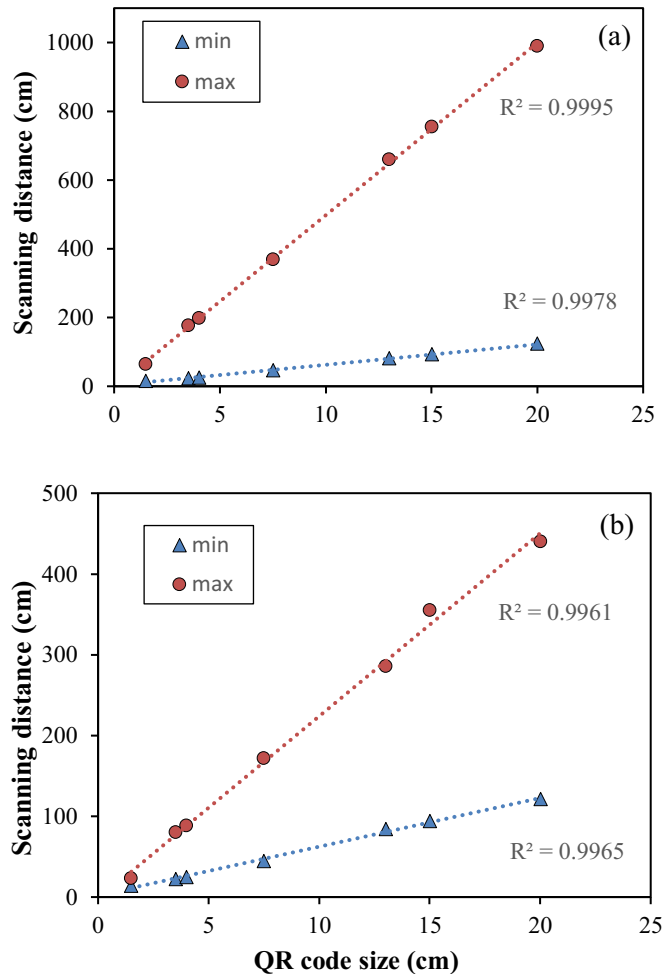


Figure 1. Simple linear regression between minimum and maximum scanning distance and QR code size. Version 3 QR code (V3) with 29x29 modules (a), Version 11 QR code (V11) with 61x61 modules (b).

These results underlined the importance of choosing an appropriate marker's type and size to encode the required information. In the farms, there are different contexts where specific information are needed. The scanning distance or the marker size may be influenced by the surrounding context and knowing the maximum scanning distance improve the labor organization.

In Table 2 are reported the results on the scanning time where significant differences were recorded among the three QR code sizes considered, that ranged on

average between 1.90 s (7.5 cm) and 2.03 s (3.5 cm). These differences are very low (0.13 seconds) and do not appear to affect farmer performances.

Moreover, the battery life was monitored during the QR code scanning tests where an overall average duration of 3 h and 28 min was recorded. This battery life could be a limit if considering the total worker hours per day (8 h). Therefore, considering the tested SG a specific and punctual use of this device should be made in the farm. Moreover, the same average battery life was detected (3.5 to 4 h) during the video call tests using both applications (App1, App2).

Table 2: Mean standard deviation (SD) and range of scanning time (s) for 3 QR code sizes. The times (s) needed to visualize on the smart glasses M400 display the information linked to the different QR code size are reported (N=2,254).

QR size (cm)	mean	SD	min	max
3.5	2.03 ^a	±0.31	1.25	3.42
4	1.98 ^b	±0.29	1.05	3.13
7.5	1.90 ^c	±0.29	1	2.94

Value with different letter in column are significantly different (P < 0.05)

The audio and video transmission lag time from the M400 to a laptop was measured to test the quality of a videocall, to evaluate the feasibility of a video-remote-assistance in real-time. The comparison of the results obtained by the two applications (Table 3) showed that the audio transmission was generally less than 0.5 seconds delay, and no significant difference was observed comparing within the transmission quality (Tq). Considering the lag time for the video transmission was observed a 0.9 second delay on average for both applications. Moreover, a significant difference of 0.7 seconds of delay between App1 and App2 was observed within the lower Tq.

Probably an important source of variation among the results on the audio-video lag time was due to the internet connection even though the same wireless connection was used for the trial. Therefore, an important aspect to take into consideration is the availability

of fast internet connection (20 Mbit/s – 30 Mbit/s) on farm, in order to support the data transfer and video streaming from the SG to a central or remote computer to minimize the delay, especially during a remote videocall.

Table 3. Lag time (s) for audio and video transmission from M400 to laptop, using Vuzix Remote Assist (App1) and Brochesia B View (App2) applications. Two transmission quality (Tq) were tested.

App	Tq	Audio (s)	SD	Video (s)	SD
1	VGA	0.55 ^{ab}	±0.60	0.55 ^b	±0.51
	HD	0.15 ^b	±0.37	0.90 ^{ab}	±0.64
2	VGA	0.65 ^a	±0.49	1.25 ^a	±0.72
	HD	0.40 ^{ab}	±0.50	0.95 ^{ab}	±0.69

**Value with different letter in column are significantly different (P < 0.05)*

In Figure 3 the results obtained from the vision acuity test using standard Snellen chart were depicted. This test allows understanding the level of image detail reachable transmitted by the SG. In this way, it is clear which type of information the farmer could share in remote assistance (with an expert, technician, another farm operator). The results underlined that a 13 mm character transmitted by the M400, from 50 cm, on the laptop screen can be read by the receiving person in any case. Setting up an HD resolution also 9 mm characters can be always recognized (100% of characters correctly recognized). On the other hand, 94% of the 9 mm characters were correctly detected at a lower resolution. Besides, it is possible to consider the 7 mm character the lowest printed size easily readable with both resolutions (HD and VGA) with 92% and 88% of the character recognized respectively. With the 4 mm character the gap between the two resolutions increases drastically. In fact, 70% of characters were detected with the HD resolution, in contrast of 15% with the lower resolution. Hence, a farmer with the M400 could share his

point of view with a high level of detail with an expert elsewhere, considering the printed character size recognizable.

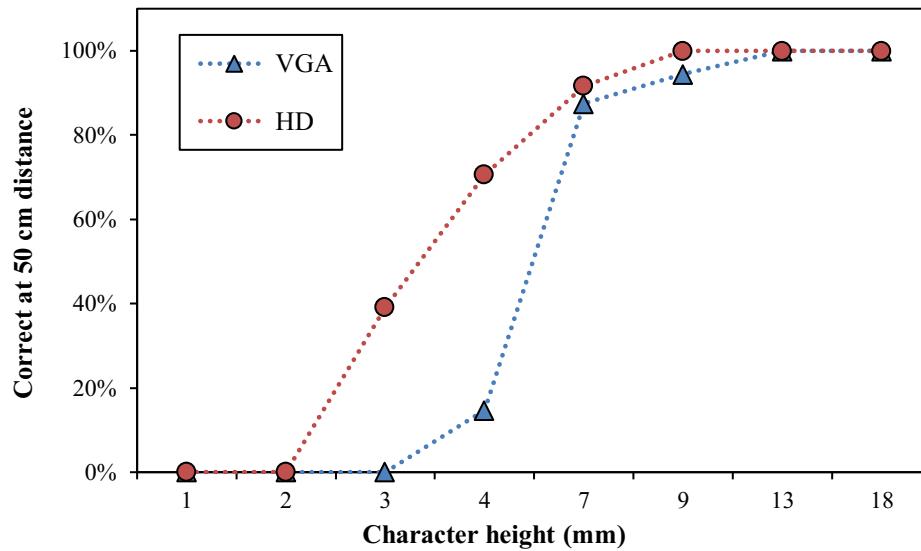


Figure 2. Percentage of correct characters read using Snellen chart transmitted on the laptop screen during a videocall from the smart glasses. Two videocall resolutions were used: VGA - ▲ - (640x480 pixels) and HD - ● - (1280x720 pixels). The distance between smart glasses camera and the chart was of 50 cm.

The interactive system of the M400 includes three buttons, a touchpad, and a vocal interaction (voice commands). Considering the voice commands, several trials were carried out in order to evaluate the performance and the capability of the M400 system to understand and respond to the voice action commands enabled (in SG) at different levels of noise. Studying an environment with a soft noise (60 – 68 dB; Alduais and Salama, 2019) was observed that all the speech commands tested were understood by the M400 that made the specific action requested (Table 4). Similar situation was observed with a noise level of 70 dB where for all the operators were recognized on average 89% of the commands. At 75 dB level of noise was observed an operator effect. In fact, it was detected that three operators had a mean of 79% of recognition rate, while the last one just 5%. Therefore, 70-75 dB represent the border points of speech commands detection

for the Vuzix M400, considering that noises greater than or equal to 80 dB do not allow the use of the voice control function.

This is an important function that, when implemented into the SG, allow to manage the device completely hands-free. Anyway, the environmental noise present during agricultural activities may limit the SG functionality.

Table 4: Action commands correctly understood (%) by the Vuzix M400 voice control function at different noise levels (dB) and for different operators.

Operator	65 dB	70 dB	75 dB	80 dB	85 dB
1	100%	89%	92%	3%	0%
2	100%	95%	65%	0%	0%
3	97%	86%	81%	0%	0%
4	100%	84%	5%	0%	0%
Average	99%	89%	61%	1%	0%

Despite Depczynski et al. (2005) that reported that only few farm conditions stay below the threshold level of 70 – 75 dB, observed for the M400 voice control test, the noise levels in specific farm situations were measured i.e., where SG might be useful. Through the sound level meter the noise related to some agricultural and livestock activities (e.g. use of tractor or milking machine) was monitored to explore in which cases the voice control function could be effectively used. Looking at the average levels of noise measured in specific agricultural situations (Table 5) and considering the range of dB where the M400 operates, the voice action commands could be used in the cabin tractor (73 kW power), in milk room and in milking parlour. In fact, the most frequent level of noise measured in the milk room and milking parlour was between 68.7 dB and 75.3 dB. Moreover, the levels over the threshold detected in these rooms (maximum levels), regarded different source of sound, e.g., the entry of the animals in the milking parlor, the opening and closing of the gates, and the animals itself. On the opposite, the speech commands resulted difficult to be used when the operator was inside the engine

room because the minimum level of decibel recorded was 93.7, that is over the threshold measured for M400.

Another agricultural working situation was monitored, involving the tractor driving. Two situations were checked, a tractor with a cabin that it is supposed to be more isolated from external noise, and a tractor without cab. The minimum level of decibel recorded allow to interact with the M400 by voice, and this level was recorded in a no working condition or when the tractors engines were running but idling. Whereas when the tractors were set in motion a level of noise over the acceptable threshold was found, as attested by the mode and maximum values recorded for both situations.

Table 5: Level of noise in decibel (dB) recorded in different livestock and agricultural working situations/places with the sound level meter

	Engine room outside	Engine room	Milk room	Milking room	Milking room 2	Cabin tractor (73 kW)	Tractor without cab (41 kW)
Min	80.8	93.7	67.3	68.6	68.7	58.5	73.6
Max	85.1	98.2	82.2	89.8	90.5	90.7	91.3
Mode	82.0	96.8	68.7	75.3	74.9	78.8	86.3
Average	82.2	96.7	71.4	76.6	76.5	76.3	84.0

** in all scenarios the machines were in operation*

3.2. Milking machine assistance scenario

In order to verify the proper operation of the milking machine installations, periodically it is needed to check the system. The ISO 6690:2007 standard specifies mechanical tests for the milking machine, to verify installation compliance and components.

In this work, a specific milking machine checking process was considered and made available in AR. The measurement process of pulsation characteristics was built on the Brochesia® portal, in the workflow section (B Step). The workflow was developed as a

sequence of step-by-step instructions that the operator must follow and interact wearing SG.

Pulsation is the cyclic opening and closing of the liner (ISO 3918). The pulsation cycle defines 4 phases: liner opening (phase a); liner open (phase b: milking); liner closing (phase c); liner close (phase d: rest). The pulsation characteristics affect the milking performance and teat condition (Upton et al., 2016; O’Callaghan, 1998). Hence, checking the pulsation characteristics as well as the milking system and components, is needed at least once or twice a year. The certified technician to verify the system compliance must use specific measuring instruments and follow several procedures depending on the test to be performed e.g., connect the sensors (flowmeter, pulsograph), disconnect some components of the milking machine (vacuum controller), etc. Commonly, the technicians are supported by a paper guide or checklist to ensure that all test procedures are performed correctly. In this context, it appears that an augmented reality procedure supported by icons and images (visual information/procedures) might be a fundamental element in learning and performing this type of tests. In addition, an SG-specific maintenance application for these mechanical tests is even more important, considering that during maintenance procedures the technicians need to make various movements and use their hands frequently.

The test regarding the pulsation characteristics consists of several steps, also related to the previous tests carried out on the milking machine. Three steps are fundamental: the connection of the sensors of the test equipment (pulsograph), recording of five complete pulsation cycles and the evaluation of the data recorded for each milking unit i.e., length of the a, b, c, d phases per pulsation cycle.

In Figure 4 the workflow scheme of the pulsation characteristics process developed on the BStep application portal was reported, following the ISO 6690:2007 standard.

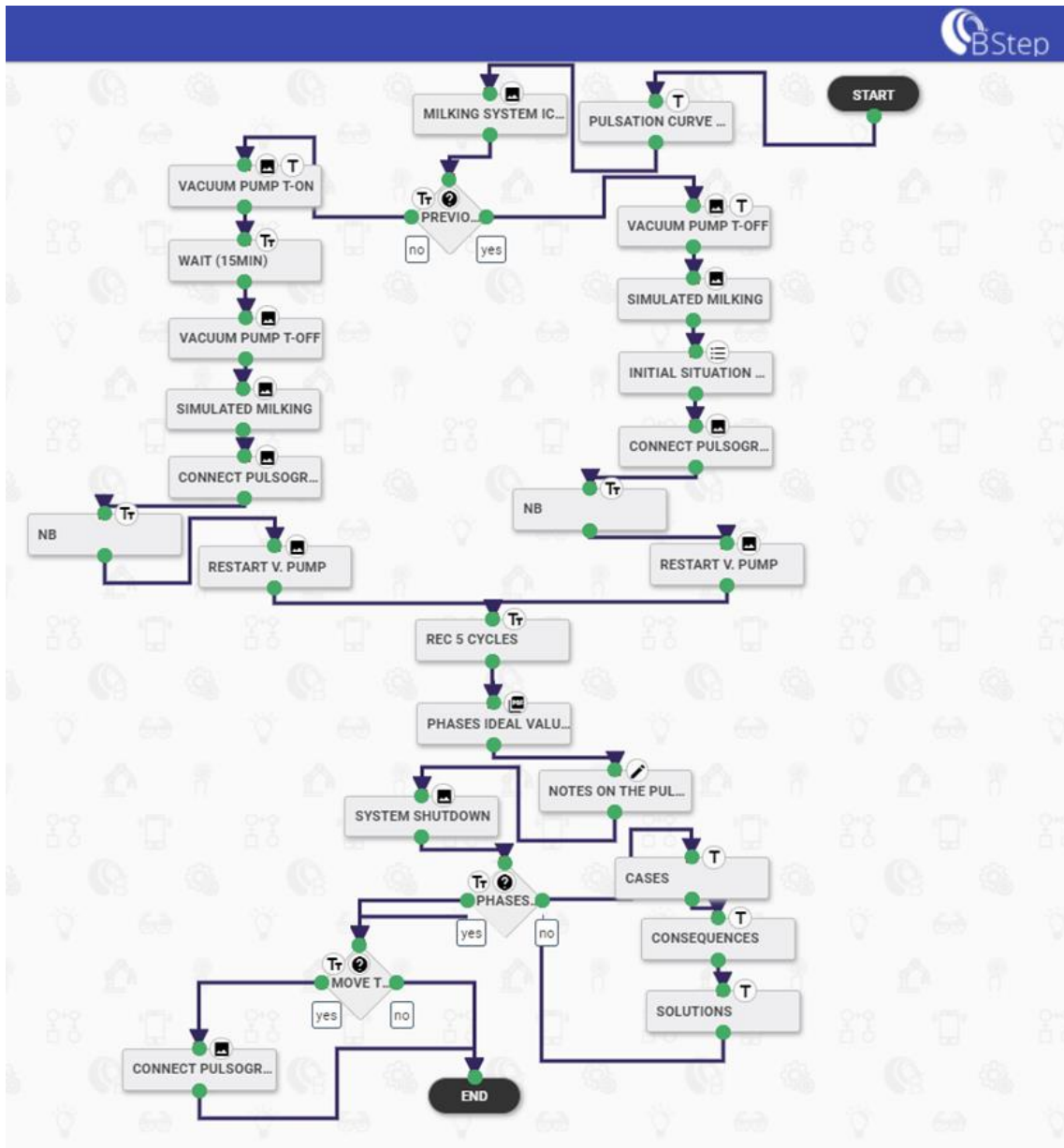


Figure 3. Mechanical milking installations tests: workflow skeleton built with the BStep application software describing the whole steps of the pulsation characteristics test.

The workflow of the pulsation characteristics test was available from a 4x4 cm QR code with 29 modules placed on the milking machine (Figure 5). The QR code represents the marker that the operator needs to scan with the SG to obtain the augmented information.

As observed in the previous tests, this type of QR code can be scanned quickly from 2 meters using the M400.



Figure 4. Operator with SG while access the maintenance augmented instructions through the QR code (4 cm), placed on the milking machine management control unit (green box).

The first augmented instruction provided to the operator was a question: *Is this the first test performed on the milking machine?* that implies that other instruments meter and configurations of the system are in place, or if he was starting from the pulsator checking. Interacting with the workflow by the touchpad of the M400 the operator can choose two ways (Figure 4). Anyhow, some preliminary steps before checking the pulsation were

needed: in one case e.g., stop the vacuum pump and set the system in simulated milking, mount vacuum regulator, disconnect the flowmeter (if previously used); in the other case turn on the vacuum pump (Figure 6a), wait fifteen minutes, set the system in simulated milking etc., as showed in Figure 6c.

Then, it was requested to attach the sensors of the test equipment with the T-piece connection and the right way it was explained through the augmented instruction (Figure 6b). Afterwards, it was indicated to record a minimum of 5 pulsation cycles with the test equipment to obtain a reliable data. The recommended values regarding the length of each phase (a, b, c, d) were visible on M400, to assist the operator during the evaluation of the data recorded in all milking units. Finally, if anomalous pulsation curves were observed the operator can view some tips and suggestion examples to solve the problem and restore the pulsation system.



Figure 5. Example of augmented information available for the M400 wearers during the mechanical milking machine test through the BStep app. a) indications for vacuum pump ignition, b) indication for the sensor attachment (T connection); c) setting the milking machine in simulated milking (moving the claw valve and closing the liner with the specific plug).

4. Conclusions

In this work the performances of a specific smart glasses (Vuzix M400) for augmented reality were evaluated from agricultural point of view. Thus, considering some features of the device (QR code scanner, AR image and video quality transmission) and the possibility to install application, a step-by-step maintenance scenario in augmented reality was developed to support technicians during the mechanical tests of the milking machine installations.

The tests underlined that the SG have a natural aptitude to be employed in the field of agricultural assistance. In fact, the results showed the capability of SG to reach the AR information from long distance (through a QR code) in short time interval and to transmit audio and video with high level of detail allowing discriminate small objects during remote assistance with reduced delay. Moreover, the tests allowed to underline that this device can be managed completely hands-free with the voice control function but only in situations with a maximum noise level of 70-75 dB, depending on the voice tone of the user.

Finally, a simulated maintenance scenario was built with an external service, representing an example of AR remote assistance application in the agricultural context. The purposed maintenance scenario underlines the potential that the AR could have in the agricultural sector to assist and guide both farmers and technicians to solve problems while working on simultaneously visualizing the information on the SG. In relation to the AR potentiality for the agricultural sector more complex, but not complicated, applications or assistance scenarios should be developed considering the farmers' needs, also thank to the implementation of the cloud computing where the AR instruction for the maintenance of agricultural machine could be stored.

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CHAPTER 4

Evaluation of Smart Glasses for Augmented Reality: Technical Advantages of Their Integration in Agricultural Systems

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Abstract

Recently, the interest in augmented reality (AR) technologies and smart glasses (SGs) has grown considerably in all production sectors. In agriculture, new technologies are being adopted to improve productivity and reduce farm inputs. From this perspective, SG are considered a valuable device to support modern farms. In the last decade, SG with different characteristics, e.g., display types, interaction methods, and features, have been developed. These aspects may affect the SG experience, leading to different performance levels for the users and from its integration on farms. The aims of this study were to compare different types of SGs for AR and evaluate the technical advantages of their integration in agricultural systems. In this work, three SGs with optical or video visualization systems were adopted. The tests were carried out on the available functionality of the SGs (e.g., QR code scanning time and distance, audio–video quality). The results showed that the devices have different performance levels in detecting markers in terms of time and distance. The audio–video quality performance was comparable for all devices, allowing them to share detailed farm information in real time. The present study demonstrated that the SG features and technical characteristics differ among devices, highlighting how these aspects should be carefully considered when selecting the most appropriate device for a farm.

Keywords: Digital Farming; Precision Agriculture; Augmented Reality; Remote Assistance; Support System

1. Introduction

Augmented reality (AR) consists of the enhancement of real objects and physical things with virtual information that could help people to work profitably or live comfortably (Milgram and Kishino, 1994; Azuma, 1997; Azuma et al., 2001). Several devices, such as smartphones, tablets, and laptops, could be used to view information in an augmented way (ElSayed et al., 2016). Smart glasses (SG) are specific devices suited for AR applications. In the last years, many steps forward have been made in the development of a wide range of SG, thanks largely to the spreading of smartphones, which has reduced the cost of microelectronic components (Höllerer and Feiner 2004; Lee and Hui 2018).

Essentially, SG are head-wearable computers provided by a display placed in front of the wearer's eye (monocular) or both eyes (binocular; Kim S. et al., 2019). Moreover, SG have been developed with different characteristics, e.g., operating system (Linux, Android, Microsoft), user interface, interaction methods (external joystick, touchpad, voice control), features (battery life, weight, camera definition, flash memory, etc.), and price. Nevertheless, one of the main discriminating characteristics concerns the visualization system, which can be an optical see-through display, composed by a semi-reflective or semi-transparent surface, where the virtual contents are projected; a video see-through display, composed by a video camera for real-world image acquisition; or a screen, where the augmented information, blended with the real environment, is shown (Billinghurst et al., 2015; Syberfeldt et al., 2017).

The process of overlaying the virtual information on the real environment can be implemented in two main ways: vision-based (marker-based) AR or sensor-based (marker-less) AR. The vision-based process uses markers (template, Data Matrix, QR Code, barcode) or landscapes to estimate and track position information, whereas the sensor-based process uses inertial, magnetic, electromagnetic, or ultrasonic sensors (GPS, gyroscope, accelerometer) to measure and pose the information (Chatzopoulos et al., 2017; Oufqir et al., 2020).

There has been a growing trend in the number of scientific papers published in the last five years (+400%) related to AR and, specifically, AR in agriculture, highlighting

the interest in this new technology in general and in the agricultural sector. The main topics of investigation for AR, with the greatest number of publications, have been the R&D of AR technologies and the healthcare, education, and industrial sectors (Muñoz-Saavedra et al., 2020; Szajna et al., 2020). Moreover, several scientific studies have focused on the integration of AR in agriculture, mainly related to the development of support systems for farmers. One of the first such studies developed a system for displaying geo-referenced yield data and NDVI on vineyards (King et al., 2005). Other applications involved the implementation of AR systems for tractor driving assistance (Santana-Fernández et al., 2010) and the use of an AR device to control the operation of two autonomous agricultural machines (Huuskonen and Oksanen, 2019). Following these, Cortazar et al., (2015) developed a system for the quantification of chlorophyll in leaves with the support of Google Glass, whereas Huuskonen and Oksanen, (2018) developed a real-time navigation system to guide the farmer in a soil sampling area. Moreover, other evidence came from the development of an AR-based application to promote sustainable development in hydroponic cultivation (Garzón et al., 2020) and for plot diagnosis activities in vineyards (Larbaigt and Lemercier, 2021). The benefits of the adoption of SG for AR in the livestock sector were shown in recent studies testing systems to support operators in farm management (Caria et al., 2019; Caria et al., 2020).

Although some scientific works on AR and SG in agriculture have been identified, the adoption of this technology by farmers is still limited. One of the main reasons is related to the fact that it is an emerging technology and little specific applications have been developed for the agricultural domain. Operational performances and SG integration in agricultural farms are still unknown. Thus, it is significant to evaluate whether these devices and the on-farm activities might be combined. In fact, recent studies confirmed that these technologies represent a promising solution in the digitalization of modern farms (Huuskonen and Oksanen, 2019; Caria et al., 2019; Caria et al., 2020). Specifically, SG require further investigation in order to support the wider use of these systems. Therefore, the evaluation of SG performances (detection of objects to be augmented, remote assistance, quality of the images displayed) highlights how different devices might be integrated to an agricultural environment and to help manufacturers to develop specific

SG for the agricultural domain. Thus, the aims of this work were to compare different types of SG for AR and evaluate the technical advantages of their integration in agricultural farms.

2. Materials and Methods

In this study, different SG for AR (Figure 1) were adopted: the GlassUp F4 (F4), produced by the GlassUp company (Modena, Italy); the Vuzix M400 (M400), produced by the Vuzix Corporation (25 Hendrix Road West Henrietta, NY 14586, USA); and the Moverio BT-300 (BT300), produced by Seiko Epson Corporation (Suwa, Japan). The three SG (SGs) analyzed share the same functionalities but different technical characteristics (Table 1). All SGs were built for professional use, particularly for the industrial sector, and tested for agricultural applications.

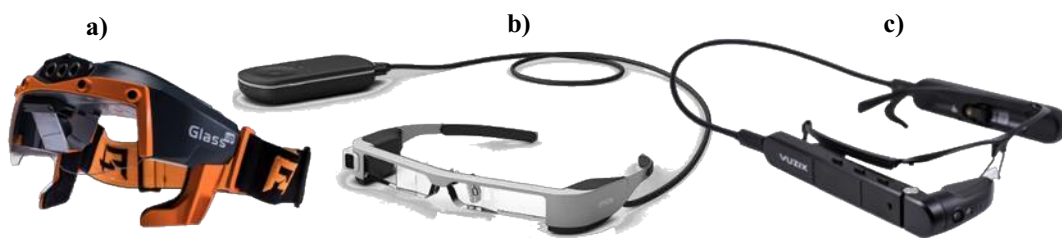


Figure 1. The three models of smart glasses used in this study: a) GlassUp F4; b) Epson Moverio BT-300; c) Vuzix M400.

The devices were selected based on their visualization systems. The F4 glasses are monocular SG with a transparent optical see-through display. The M400 glasses are also monocular SG, but with video see-through display. Instead, the BT300 glasses are binocular SG with a transparent optical see-through display. The SGs tested also have different interaction systems, such as an external joypad, touchpad, and key button, and different frame designs.

Table 1. Technical features of the smart glasses used in this study (as reported by the producers).

Item.	F4	M400	BT300
Processor	Cortex A9	8 Core 2.52 GHz Qualcomm XR1	4 Core 1.44 GHz Intel Atom
Flash memory	8 Gbytes	64 Gbytes	16 Gbytes
Operating System	Linux	Android 8.1	Android 5.1
Display	LCD (on right eye) Full color 640 x 480	Occluded OLED, 24-bit color, 640x360	Si-OLED 24-bit color, 1.280x720
Field of view	22°	16.8°	23°
Sensors	Accelerometer, gyroscope–compass (9 axis), lux sensor	Accelerometer, Gyroscope, magnetometer (3 axis)	Accelerometer, Gyroscope, magnetometer (3 axis), lux sensor
Connectivity	Wi-Fi, Bluetooth	GPS, Wi-Fi, Bluetooth, USB-C	GPS, Wi-Fi, Bluetooth, micro-USB
Camera	5 Megapixel, 15fps	12.8 Megapixel, 30fps	5 Megapixel
Battery Life	6–8 h	2–12 h	4 h
Controller input	Joypad, one button on the glasses	Touch pad, 3 buttons, voice command	Joypad (touch pad)
Weight	251 g	190 g	69 g

To compare the performances of the devices, several tests were carried out at the laboratory of the Agricultural Sciences Department, University of Sassari (Italy). The experiments involved the common functions of the SGs, such as the scanning of AR markers (QR codes) and audio–video transmission. Moreover, the battery life during the tests was monitored.

2.1. QR code scanning tests

The default scan function, available to all devices tested, was used to compare the performances of the SGs in detecting augmented information. The selected AR marker was a QR code in which the farm information was embedded. Two different QR code trials were carried out in order to assess the scanning time and the scanning distance.

The scanning time trial consisted of measuring the time needed to display on the SGs the augmented information associated with the markers. The time frame included the tasks going from scan function activation to data visualization on the SGs display. Specifically, the scan time was measured by an operator who started measuring at SGs scan function activation and ended once the wearer visualized the AR information. In these trials, three different printed sizes of the QR code were adopted: 3.5 x 3.5 cm (3.5), 4 x 4 cm (4), and 7.5 x 7.5 cm (7.5). The scans were carried out at a 40 cm distance from the QR codes placed in a vertical plane (wall) and the SGs wearer was in front of the marker.

The scanning distance trials involved measuring the minimum and maximum distances at which the QR codes were detectable from the SGs' cameras. The printed sizes of the QR code used were 1.5 cm, 3.5 cm, 4 cm, 7.5 cm, 13 cm, 15 cm, and 20 cm per side.

For both experiments, two different versions of QR codes in terms of the number of modules (black and white squares) were tested, to assess whether the density of the marker might affect the scanning performance. Simple (SI) and complex (CX) QR code types were generated for each device, with 29 x 29 modules and 61 x 61 modules, respectively (Figure 2). In the CX codes, farm information was encoded directly in the

QR code itself, using 272 characters. In the SI codes, the same information was written on a file (i.e., a PDF, web page), while the file name or web page link was encoded in the QR code itself. The markers were placed on the vertical plane at eyes level for both tests. Moreover, the scanning tests were performed in the morning from 9:00 to 13:00 at the laboratory with standard lighting conditions.

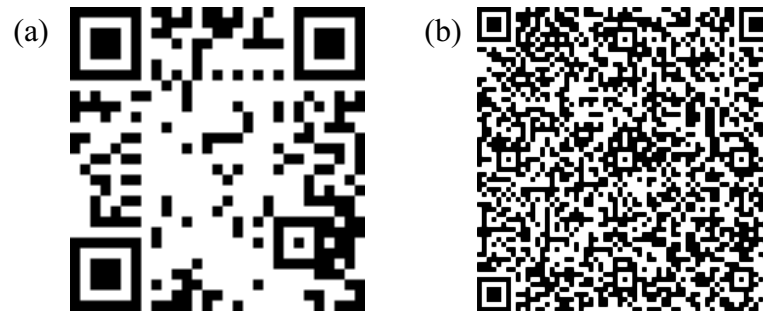


Figure 2. Example of the two types of QR codes adopted during the trials: a) Simple (SI); b) Complex (CX).

2.2. Audio–video quality transmission tests

Two tests were performed to evaluate the audio–video quality of the transmitted audio–visual contents from the SGs to a remote device (PC). These trials were carried out using a VoIP (Voice over Internet Protocol) call apps, available in all devices considered.

The first test measured the lag time between the SGs and laptop, in order to evaluate the delay during the transmission of video and audio contents. The lag time was measured by synchronizing the clocks of the two operators (SGs wearer and PC operator) and recording the time frame between the emission and receiving times of predetermined contents (Muensterer et al., 2014).

The second test assessed the observable level of detail of transmitted images through the SGs. The visual acuity tests were performed using a standard Snellen chart, composed by eleven lines with decreasing size letters blocks. The printed chart was placed at 50 cm from the SGs and displaying the characters on the laptop’s 16-inch screen. The outputs of the test were recorded along with the decreasing size of the characters (Muensterer et al., 2014).

The lag times were measured with 20 replications, whereas the Snellen chart test were performed with 3 replications from different operators.

2.3. Battery life Test

During the trials, the battery life was monitored to evaluate the battery autonomy of the SGs with one charge cycle. Two working situations were evaluated: SGs exclusively running the scan function to detect the markers and open the augmented information, and SGs running mixed functions (scanning, video calling, etc.).

2.4. Statistical analysis

Descriptive statistics were calculated and reported for the QR code performance tests and for the lag time tests. Due to the non-parametric data trends the Kruskal–Wallis rank sum test and post hoc multiple comparison ($P < 0.01$) were adopted for the scanning time and audio–video quality transmission data to make comparisons between treatments. The analyses were performed using R software (version: 4.0.5).

3. Results and Discussion

3.1. QR code scanning performance

The QR code scanning tests represent a primary step in understanding the capabilities of the SGs to detect and provide AR information to farmers in the field. In fact, the markers could be coupled with several production units (crops, animals, orchards, protected crops) and farm contexts (open field, milking parlor, greenhouse, etc.). Furthermore, the use of QR codes in agriculture is usually coupled with the traceability of food products (Bai et al., 2017; Tarjan et al., 2020) showing its potential applications in providing accurate information for the logistics of products through the supply chains (Gebresenbet et al., 2018), for storage animal husbandry records (Green et al., 2017) and the management of vegetable productions (Yang et al., 2018).

The three SGs were compared, and each device was observed to perform differently by detecting QR codes at different speeds and distances.

Table 2 shows the results of the QR code scanning times. Different performance based on the type (SI, CX) and size of the codes was recorded among the three devices tested. Overall, the best performance was recorded for the M400, which required an average of 2.00 s to show the augmented farm information in the SG display. Moreover, the QR code type did not influence the scanning time within the three QR code sizes. Considering the BT300, the scanning time for the SI codes was, on average, 6.10 s, where a difference was found in the 7.5 cm CX code (3.83 s). The other two CX QR codes (3.5 and 4 cm) were not detected by the BT300 SG. The scanning time for the 7.5 cm CX code was lower than those for the SI codes. This result was due to the fact that in the CX code, all the farm information was directly encoded into the QR code. Therefore, the information was available faster, although it was only possible to encode a limited number of data (259 alphanumeric digits). The F4 showed a scanning time of about 9.50 s, and a significance difference was found comparing the 3.5 and 4 cm QR code sizes. However, the code type did not influence the scanning time within the size classes tested.

The time required to display the augmented information on SGs in an agricultural work context represents one of the parameters that might influence the farmer's performance and productivity. The ability of the SGs to display specific AR information in a short time allows these devices to be implemented in farm routines, increasing work efficiency and precision (e.g. selecting animals during the milking sessions). In this way, the SG can support the farmer in the identification of food stocks to be selected for the preparation of the animal diet and, also, for the identification of animals with specific information (milk yield, health status, etc.; Caria et al., 2019; Caria et al., 2020).

Table 2. Average scanning times (s) and standard deviations (SD) of different sizes and types (SI = simple, CX = complex) of QR codes for the three devices (F4, BT300, M400).

QR size (cm)	3.5		4		7.5		Tot. scan
Device	SI	CX	SI	CX	SI	CX	N
F4	12.03 ^{aA}	12.12 ^{aA}	8.10 ^{bA}	8.99 ^{bA}	7.28 ^{bA}	7.46 ^{bA}	288
SD	±6.10	±4.33	±2.76	±3.33	±3.26	±0.93	
BT300	6.02 ^{aB}	-	6.28 ^{aB}	-	6.19 ^{aA}	3.83 ^{bB}	192
SD	±1.02	-	±1.22	-	±1.02	±0.83	
M400	2.05 ^{abC}	2.05 ^{abB}	1.99 ^{abC}	2.09 ^{aB}	1.84 ^{bB}	1.90 ^{abC}	288
SD	±0.34	±0.35	±0.28	±0.33	±0.31	±0.31	

^{a-b} Mean values in the same row with diverse lowercase superscripts are statistically different ($P < 0.01$).

^{A-C} Mean values in the same column with diverse capital superscripts are statistically different ($P < 0.01$).

Figure 3 shows the results of the QR code scanning distances for the SGs. This test highlights the distance at which augmented farm information might be detectable with different AR devices through a specific marker. Considering the QR code types, regardless of the size, the SI codes were detected at greater distances than the CX codes for all devices. The BT300 was not able to scan the CX codes of size less than or equal to 4 cm, whereas the F4 and M400 were able to detect 1.5 cm QR codes, though only at close distances (up to 5 cm and 22 cm, respectively). The highest scanning distances were measured for the M400 considering both QR code types (SI, CX). Combining this device with an SI code (29 modules), it was possible to gather the augmented information at about 2 m, using a marker of 4 cm size. Likewise, a 20 cm QR code can be scanned at about 10 m away. Moreover, a strong linear trend between scanning distances and QR codes size was observed for all the SGs and QR code type. The coefficients of

determination (R-squared) were all over 0.96, specifically: F4 SI (0.964), F4 CX (0.996), BT300 SI (0.997), BT300 CX (0.986), M400 SI (0.999), M400 CX (0.996).

The minimum scanning distance was recorded for all devices and QR code types. The ratio between the scanning distance and QR size was constant for the two types of code, where the minimum distance was strictly dependent on the camera frame of the device. The QR code types influenced only the scanning distance due to the higher number of modules making the CX marker more difficult to distinguish at a greater distance. Thus, when the farmer needs to gather AR information from long distances (e.g., from a tractor cabin), it is recommended to adopt simple-type QR codes with distance-related printed size and select suitable SGs with high scanning performance.

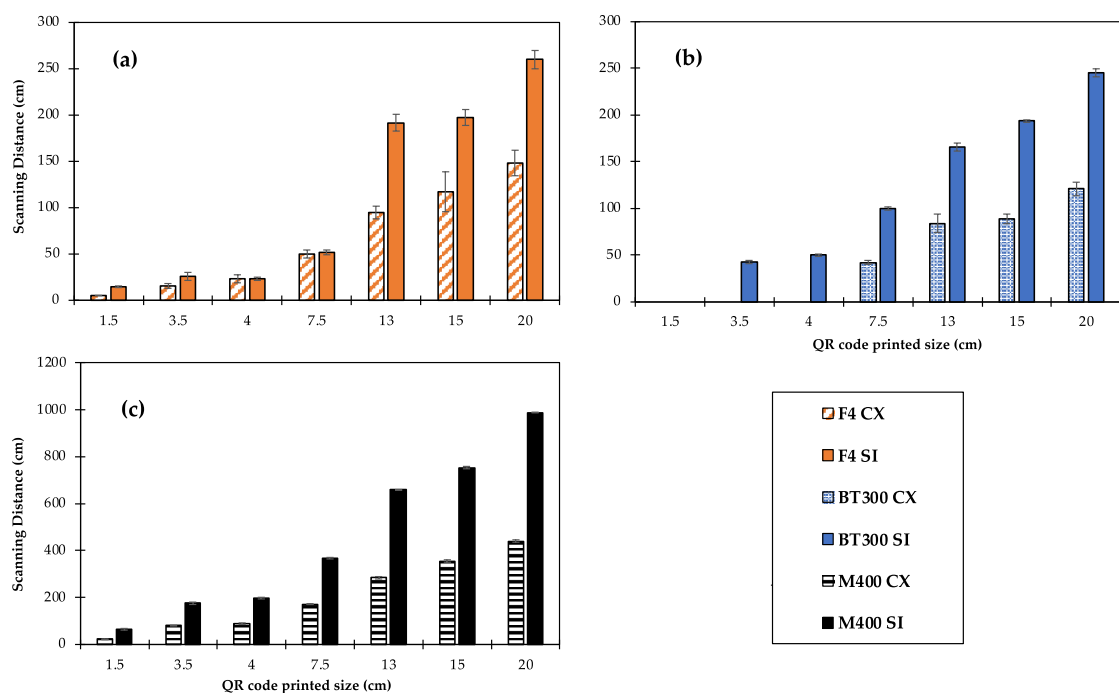


Figure 3. Maximum scanning distance of the two QR code types with increasing printed size: Simple QR (solid color fill) and Complex QR (pattern fill) for the three SG tested: a) GlassUp F4; b) Epson Moverio BT-300; c) Vuzix M400.

3.2. Audio–Video Quality transmission performance

Table 3 reports the results on the lag times recorded during video calls between the SGs and a laptop. Comparing the three devices, the M400 and the BT300 had less than one second of delay for both audio and video transmission. On the other hand, the F4 showed a significant delay of greater than 1 s for audio transmission and greater than 2 s for video transmission. The negligible lag times obtained for all SGs tested might allow the farmer to share their point of view with technicians (agronomist, veterinarian, mechanic, etc.) during maintenance procedure of on-farm machineries. Moreover, the farmers could be guided during these activities in real-time in an interactive way.

Table 3. Average lag times (s) and standard deviations (SDs) in transmitting audio and video contents from smart glasses (F4, M400, BT300) to a laptop during a video call.

Device	Audio (s)	SD	Video (s)	SD
F4	1.24 ^a	±0.81	2.21 ^a	±0.11
BT300	0.43 ^b	±0.81	0.55 ^b	±0.68
M400	0.44 ^b	±0.22	0.91 ^b	±0.29

^{a-b} Mean values in the same columns with diverse superscripts are statistically different ($P < 0.01$).

The results of the video quality tests are shown in Figure 4. Overall, the SGs tested were able to clearly distinguish characters greater than or equal to 13 mm in size. The BT300 and F4 showed better performance, allowing users to completely discriminate characters of size greater than or equal to 7 mm. Moreover, the BT300 enabled to distinguish 4 mm characters in 96% of cases, unlike the other SGs (78% and 43%, respectively, for F4 and M400). These outcomes confirm the capability and feasibility of these devices in remote assistance operations, ensuring a high level of detail of the contents transmitted.

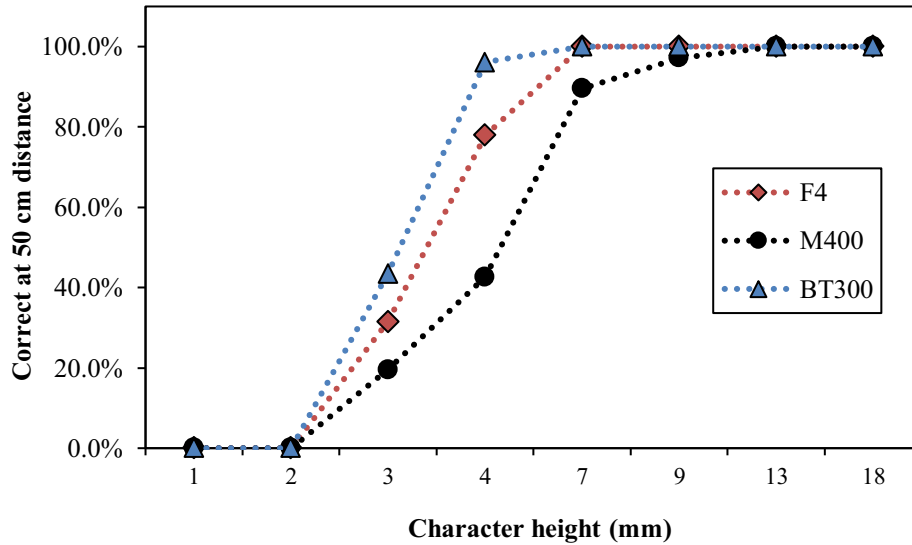


Figure 4. Visual acuity test results, showing the percentage of correct letters read on the laptop screen during a videocall from the smart glasses.

Furthermore, the field of view (the area where AR contents are showed to users) and the visualization system (optical or video) might influence the use of SG in the farming working environments. As reported by Syberfeldt et al., (2017) a minimum of 20 degrees of field of view are necessary in an industrial working context to avoid discomfort to the users and limitation on the amount of AR information vision (Kim, M. et al., 2019). Concerning the visualization system, optical see-through display, allows wearers to directly see the real world using both monocular or binocular SG. On the other hand, SG equipped with video systems display have disadvantages due to the latency of the reality vision, especially for binocular devices. These drawbacks, linked to the nature of this system, might rise concerns to the safety of the users by creating a blind spot in the operator's real field of view (Syberfeldt et al., 2017).

3.3. Battery life

Table 4 presents the results on the SGs' battery life. All the devices had shorter battery lives in a mixed-use situation than in scanning activities. Specifically, the BT300 and M400, compared to the F4, showed greater differences in SG battery autonomy

between the usage types (12 and 18 min, respectively). The F4 showed the best performance in terms of battery life, with a battery autonomy of about 7 h. This fact was probably due to a set of characteristics that differentiate the F4 device, such as, the simplest user interface, operation mode, etc. that could influence the energy uptake [30]. However, considering the results obtained, the battery life does not represent a limitation in the usage of SGs in agricultural activities. In fact, the devices tested might support the farmer during specific tasks, e.g., selecting animals, feed preparation, remote assistance in the field, etc. (Caria et al., 2019; Caria et al., 2020).

Table 4. Battery life expressed in working hours (h) of the three smart glasses (F4, BT300, M400) considering two types of usage situation: Scanning (repeated QR code scans) and Mixed-Use (scanning, video calling, other).

Device	Usage type	
	Scanning (h)	Mixed-Use (h)
F4	6.91	6.87
BT300	2.32	2.02
M400	3.58	3.37

4. Conclusions

SGs are promising and innovative devices, especially when implemented in production and professional contexts. However, several challenges need to be addressed to support their wider use in the farming domain. In fact, the availability of specific software for agricultural contexts (e.g., to help farmers in the management of feedstocks, animals, crops, operating machines and tractors) are still limited. Moreover, another challenge will be to enhance the inter-communicability of SG with other smart tools available in the farm also using IoT technologies, as reported by Phupattanasilp and Tong, (2019). Nowadays, there are numerous models of SGs available in the market and ready to use; nevertheless, it is important to know their specific performance levels and capabilities in order to properly integrate them into agricultural production contexts. In this study, we compared three different SGs for AR and tested their main available

functionality (e.g., scanning codes, video calls, etc.), from an agricultural use perspective. Overall, the results showed that the SGs might enable farmers to obtain fast and precise augmented information through the use of markers placed in different points on the farm.

However, the SGs adopted in this study presented a wide range of performance, especially in the detection of QR codes of different printed sizes and amounts of information encoded. The audio-visual transmission quality allowed for the discrimination of small details during remote assistance applications. Moreover, the battery autonomy of the SGs ranged from 2 to 7 h per charge cycle of the battery, where the type of usage might influence the battery life. This study highlights that SGs represent a valid tool to support farm management. Moreover, for each device tested, the strengths and weaknesses for a farming use in relation to their performances and technical features are shown in Table 5.

Finally, to encourage the spread of these technologies in the agricultural domain, it is necessary to extend and improve internet access in rural areas that represent one of the main concerns that could influence and increase even more the digital divide especially for the rural areas (Trendov et al., 2019). In fact, the availability of a high-speed internet connection is essential to optimizing the performance of these technologies. In future studies, the authors will be focused on the development of specific system for the agricultural domain that aims to integrate and manage farm data and to support the agricultural operators, providing timely information through augmented reality devices.

Table 5. Strengths and weaknesses of the three SGs tested for its integration in the farming domain and considering their functions and structural parameters.

Parameter/ function	Farming application/ implication	F4	BT300	M400
Battery life	High battery life, reduced recharge times or interchangeable batteries (M400) allow continuous field use with less loss of time.	+	-	+ -

Marker detection (time/distance)	Obtaining overlap information on animals, plants, crops, agricultural machinery, in a reduced time interval or at high distances could increase the farmer efficiency.	-	+ -	+
Audio-Video Transmission	Transmitting images and audio with good quality (clarity, timing, detail) could improve and expand remote technical assistance to farmers in the field.	+	+	+ -
Field of View	Limited field of view, < 20°, (Syberfeldt et al., 2017) could negatively influence the farmer use of SG while working.	+ -	+	-
Visualization System	The system could affect the farmer's safety by limiting the farmer's field of view, especially in the case of binocular or video see-through systems	+	+ -	-
Weight/comfort	Normal glasses weight about 20g, an excessive or unbalanced weight of SG could negatively affect its use by farmers	+ -	+	-

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CHAPTER 5

Performance and Usability of Smart Glasses for Augmented Reality in Precision Livestock Farming Operations

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Abstract

In recent years, smart glasses for augmented reality are becoming increasingly popular in professional contexts. However, no commercial solutions are available for the agricultural field, despite the potential of this technology to help farmers. Many head-wearable devices in development possess a variety of features that may affect the smart glasses wearing experience. Over the last decades, dairy farms have adopted new technologies to improve their productivity and profit. However, there remains a gap in the literature as regards the application of augmented reality in livestock farms. Head-wearable devices may offer invaluable benefits to farmers, allowing real-time information monitoring of each animal during on-farm activities. The aim of this study was to expand the knowledge base on how augmented reality devices (smart glasses) interact with farming environments, focusing primarily on human perception and usability. Research has been conducted examining the GlassUp F4 smart glasses during animal selection process. Sixteen participants performed the identification and grouping trials in the milking parlor, reading different types of contents on the augmented reality device optical display. Two questionnaires were used to evaluate the perceived workload and usability of the device. Results showed that the information type could influence the perceived workload and the animal identification process. Smart glasses for augmented reality were a useful tool in the animal genetic improvement program offering promising opportunities for adoption in livestock operations in terms of assessing data consultation and information about animals.

Keywords: milking system; precision agriculture; sheep; workload index; feeding; breeding

1. Introduction

Augmented reality (AR) is a relatively new technology that allow superimposing virtual objects (computer-generated graphics) over the real world. The term AR was born in the 1990s from Caudell and Mizell (1992), at which time AR was classified for the first time into the virtuality continuum “space” that includes other hierarchical levels such as the environments, augmented virtuality and virtual environments. In this classification, AR is closely-related to the real environment that is augmented—not replaced—with computer-generated objects. This is in contrast with augmented virtuality that expands virtual environments with real elements. In general, when real and virtual objects are simultaneously accessible in a display, we refer to this as mixed reality (Milgram and Kishino, 1994). Likewise, the concept of AR may be applied to all those technologies, e.g., PCs, laptops, tablets, smartphones and wearables that combine and register (align) 3D physical and virtual objects in tangible environments, and in real-time (Azuma et al., 2001). The importance and strength of an AR system lies in its ability to provide information to users that otherwise would not be available to the handler’s senses and help them in solving tasks at the same time (Azuma, 1997).

Moreover, a branch of AR supported from portable devices is named mobile augmented reality (MAR). A MAR system has the same characteristics of an AR system and otherwise display the augmented contents on a mobile device. As a result of their nature, the most important MAR devices are smartphones, tablets and smart glasses. Currently the MAR world is predominantly associated with hand-held devices such as smartphones and tablets, due to their high portability, reduced dimensions (in particular mobile phones) and social acceptance. However, in the near future, they are expected to be replaced by smart glasses (SGs), since they enable users to visualize computer-generated contents without the use of hands and on a front display (Chatzopoulos et al., 2017; Höllerer and Feiner, 2004). Some reports suggest there will be an exponential growth of the AR and Virtual Reality (VR) market and of the number of SG distributed by 2025 (Tractica, 2019; Bellini et al., 2016).

The first SG prototype was developed in 1997 for urban exploration and consisted of several devices (wearable see-through display, handheld computer, GPS receiver, desktop

computer in the back, etc.) brought to the user (Feiner, 1997). It was a cumbersome system in contrast with the actual SG available devices.

Currently, smart glasses are essentially head-wearable miniature mobile computer that provide a see-through display, at eye level, where the augmented content (e.g., image, text, video) is projected without occluding the real-world view. Several companies are developing SG devices for AR with large differences in design, incorporating technology and existing functions. In particular, we can differentiate SGs by optical/video see-through display, available sensors (accelerometer, gyroscope, magnetometer, GPS, etc.), tangible interface (external controller, trackpad and button), operating system (Android, Windows, Linux), processors, memory, battery life, weight, field of view and price (Lee, and Hui, 2018; Syberfeldt et al., 2017). These overall features are important factors that can affect the SG-wearing experience, leading to different acceptance levels by the users. Another important element that characterizes an AR system is the tracking and registration process that allow to superimpose the virtual object on the physical ones with several methods. This process can be sensor-based (inertial, magnetic, electromagnetic and ultrasonic method) and video-based (marker-based, feature-based method). Another one can be the hybrid method, which blends the previous systems to reduce their limitations (Chatzopoulos et al., 2017).

In recent years, AR technology and SG devices are being increasingly tested, especially in professional contexts, such as the industrial (Fraga-Lamas et al., 2018; De Pace et al., 2018), medical (Eckert et al., 2019), educational and research sectors and many others like the agricultural sector (Huuskonen and Oksanen 2018; Kumar et al., 2018; Cupial, 2011), besides the SG producer companies, are more focused in developing solutions primarily for manufacturing and engineering field (Vuzix, 2019; Epson, 2019; GlassUp, 2019). Interestingly, however, one of first widespread AR results was in the entertainment field with Pokemon Go smartphone application (Shea et al., 2017).

Nevertheless, there are usability problems related to human-machine interactions that can limit the spread of SG devices for AR technology (Kim et al., 2019; Lee and Hui 2018). These are linked to low computational power and that the available applications are still

basic (Chatzopoulos et al., 2017), thus the final user may have problems with using the SG if proper applications related to his field of work are not available.

Over the past decades, dairy farms have adopted innovative technologies to improve their productivity, profit and animal welfare (Halachmi et al., 2019; Todde et al., 2016). Modern milking systems allow recording of milk yields, milking times, electrical conductivity, milk flow rates and alarms for each animal (Caria et al., 2019b; Todde et al., 2017). Currently, the level of technology available largely differs according to dairy-producing species. Dairy sheep farms, for instance, have the lowest technological potential, with a majority relying on conventional milking systems.

Historical knowledge and individual productivity are fundamental for flock grouping (Valergakis et al., 2008), especially for feeding strategies (Wu et al., 2019; Lobeck-Luchterhand et al., 2014) and genetic improvement programs (Kariuki et al., 2017), which consist of identifying and grouping animals with predetermined characteristics (mainly milk yield and prolificacy). Moreover, these programs require a considerable amount of human, animal and material resources (Camara et al., 2019; Leroy et al., 2017). The identification and grouping of animals for breeding purposes is often highly labor-intensive, commonly involving from two to three operators. It is normally performed in a milking parlor during the milking session. Therefore, the accessibility of real-time information (e.g., milk yield per year, number of live offspring per parturition, etc.) per single animal represents a valuable step forward for breeders. Consequently, linking the individual information of each animal to SG for AR may prove useful for dairy farmers, allowing the completion of work tasks with less workforce thanks to the free use of both hands (Okayama and Miyawaki, 2013).

To support the effective and safe agriculture adoption of smart glasses for augmented reality, there is a need to provide evidence-based results for SG use in on-farms activities. Additionally, the information type, such as colors and symbols used in a user interface may affect work performance (Baumann et al., 2011).

However, the scientific literature to date fails to address the application of augmented reality in livestock farms. Previous research has highlighted the influence of SG design/category and data composition type on worker safety and performance (Kim, S. et

al., 2019; Liu et al., 2009; Patterson et al., 2006) and on the obstacles crossing strategies adopted to the wearers to minimize the trip risks (Kim et al., 2018).

Moreover, the information disposition on the see-through display and walking/sitting behavior affect the text comprehension on the SG (Rzayev et al., 2018). Nevertheless, more studies are needed to support the widespread diffusion of SG for AR in the agricultural and livestock field.

The overall aim of this study is to extend the breadth of knowledge on the interaction of AR devices with a farming environment. Specifically, this work focuses on: i) the feasibility and performances of animal identification for grouping activities using smart glasses for augmented reality; ii) the human perception and the usability of smart glasses in on-farm activities. Moreover, the composition of the animal information (i.e., text vs. graphic) displayed through a commercially available SG was also evaluated.

2. Materials and Methods

2.1. Task Equipment and Participants

The GlassUp F4 smart glasses (F4SG), produced by an Italian company (GlassUp, Modena, Italy), were used in this study. The F4SG were selected for their features, specifically, since they were certified IP31 (International Protection for solid particles and liquids ingress), they came with protection lens and an elastic band to ensure that the glasses remain in position. Thus, this device was particularly suitable to perform, both indoor and outdoor, agricultural on-farm activities—also demonstrated by the results of a recent study, where the F4SG were tested in laboratory and field environments (Caria et al., 2019a). The F4SG are combined with an external joypad named “box”. It provides energy and allows control of the glasses via navigation buttons (enter, clear, arrows up, down, etc.) and five function keys that can be set with various tasks, such as front lighting, photo capturing, video recording and scan-code function (Figure 1).



Figure 1. GlassUp F4 smart glasses used in this study: (1) frontal protection lens; (2) right side key button; (3) video/photo camera; (4) front light; (5) optical system/see-through display; (6) joypad “box”.

Only the latter function was utilized in this study to scan Quick Response (QR) codes containing information linked to individual sheep. These particular smart glasses allow storing files (image, text, video, audio) on the flash memory. Each file was associated to a unique QR code that once scanned allow to see the augmented file on the SG display. This process could be performed also without internet connection. The scan-code function was coupled to the right-side key button on the F4SG to render task flow more efficient.

The evaluation trials were carried out at the Agricultural Research Agency of Sardinia (Italy) at the Bonassai Animals Research Station (AGRIS). The task consisted of identifying and selecting animals during milking that are well-suited for genetic improvement programs based on the information provided by the QR code of each ewe. The work was realized in the milking parlor with 16 participants, as found in a similar study (Kim, S et al., 2019). The age range, mean and standard deviation (SD) of the participants were 29–62 and 48.4 (8.3) years, respectively. The education level of the participants was: middle school title (31%); high school diploma (31%); bachelor’s degree for (38%). All the participants were expert milkers working with the milking

machine. All participants received a training session the day preceding the trials that explained the underlying concept of AR and demonstrated the functions and operation of the F4SG. The trials were conducted in the DeLaval MidiLine milking system composed of 24 groups for 48 stalls with an automatic cluster removal and a pit height of 85 cm.

2.2. Sheep Information Sheet and QR Code

In regard to user interface scheme, two types of documents were created containing information on sheep identification (ID), yearly milk production, health status, body condition score (BCS), warning message and other related data. The first type was text format (TXT) with information summarized in a table. The second type was graphic format (GRH) where the same information was outlined with the aid of illustrations and graphics. Specifically, the augmented visual stimuli presented to the farmers, in the graphic format, consisted in four main representative images adopted to represent the identification number (ear tag), the milk yield (milk churn), the number of birthed lambs (stylized lambs) and the warning message (animal crossing sign). Moreover, a graph representing the evolution of the milk lactation curve along to the body condition score has been included in the GRH format. The QR codes had 21×21 modules and they were printed with a size of 4 cm per side. The QR code size was based on the average distance between the QR code and the milker wearing the SG. As suggested by Caria et al., (2019a), the optimal scanning distance between the QR code and the device corresponded to ten times the QR code size. The QR code was scanned from the F4SG camera and once it has been identified the linked information sheet was opened and showed on the optical see-through display. In order to avoid delays during milking procedures, the individual QR codes were placed on a specific support at the same height as the sheep's tail corresponding to 150 cm from the ground (Figure 2).

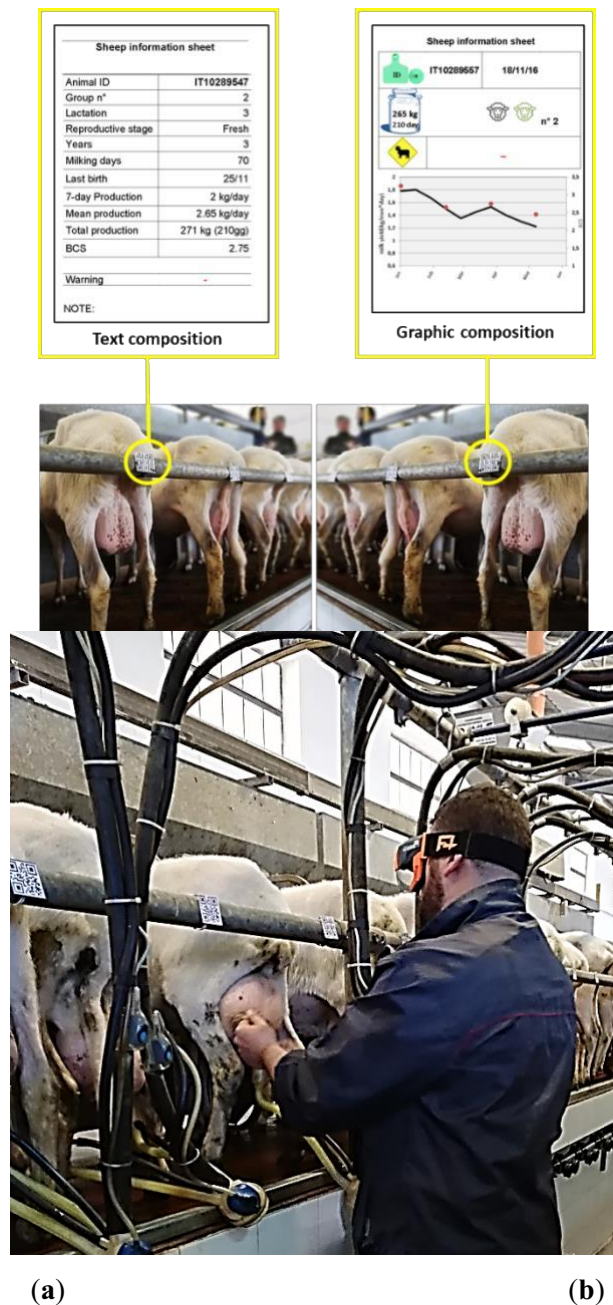


Figure 2. Sheep information sheet text and graphic format (a) and participant reading an animal's information on GlassUp F4 smart glasses (F4SG) while milking (b).

2.3. Experiment and Evaluation Procedure

The task was performed in the milking parlor and consisted of the identification and selection of sheep with milk production exceeding 250 kg/year. For the identification and

selection, SG was used, and the operator visualized the augmented information of the sheep during milking processes (Figure 3). The operator had to scan the sheep QR code to visualize the individual datasheets and identify the ewes that had high milk yield. The task duration and the error rate in sheep identification were monitored. After having scanned 48 sheep, each milker was asked to complete two questionnaires. The first one was the NASA Task Load Index (NASA-TLX) (Bracco and Chiorri, 2006; Hart, 2006) used to evaluate perceived workload among info mode while visualizing TXT information or GRH information on SG optical display, as also observed in other studies (Kim, S. et al., 2019; Wang et al., 2019).

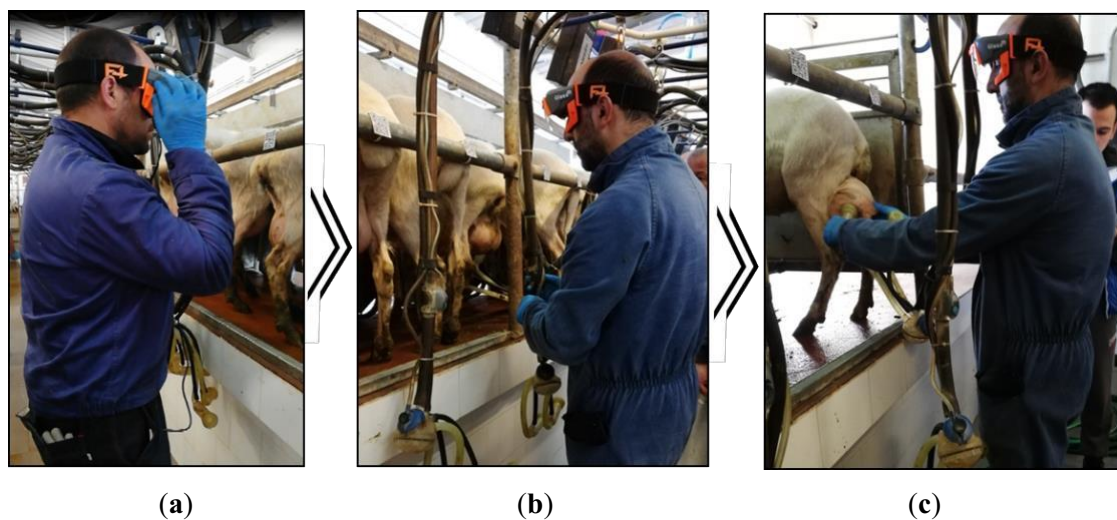


Figure 3. Operation flow carried out in the milking parlor: QR code scanning function activation (a); QR code reading (b); information visualization and animal identification/selection while milking cluster attachment (c).

The second questionnaire was the International Business Machines (IBM) Computer System Usability Questionnaire (CSUQ), considered a universal tool that encompasses all the usability criteria that we need for the evaluation of the system (effectiveness, efficiency, satisfaction, discriminability, etc.) (Assila et al., 2016). The CSUQ was adopted to evaluate the SG ease-of-use for animal selection and identification

(Lewis, 1995). The CSUQ comprised four categories: system usefulness (SYSUSE); information quality (INFOQUAL); interface quality (ITERQUAL); overall satisfaction (OVERALL). We adapted the original statements to our evaluation purpose; we asked how much the participants agree with this statement in a five-point scale: 1 strongly disagree, 2 disagree, 3 neutral, 4 agree and 5 strongly agree (Kim, S. et al., 2019). Table 3 reports the CSUQ revised statements used.

2.4. Statistical Analysis

Descriptive statistics (arithmetic average, standard deviation) were calculated for each of the weighted scores of the NASA-TLX based on scale of 0–100, for each statement and categories scores of the CSUQ. Statistical analysis was carried out by comparing the overall scores of the NASA-TLX between info mode, using the Wilcoxon Rank-Sum Test due to non-parametric data trends. To perform the statistical analysis the R Studio software (version: 3.4.4) was used.

3. Results and Discussion

Each milker scanned and read 48 files during milking operations to select animals with high levels of milk yield. Grouping ewes are generally performed several times per year during the milking routine and the time to complete this task depends on the number of operators involved. Conventionally, two operators—as well as the milkers—are needed, one to read the animal ID and another to read the related information. The smart glasses for AR enabled to conduct animal selection and grouping, during milking procedures, involving only one working unit instead of three, obtaining a work completion time per side (24 milking stalls) averaged 11.1 min (Table 1).

When the milking routine is modified by the addition of a new task, such as pressing a button and scanning a code, the milking operating time invariably increases. In fact, the milking sessions with a conventional routine, where only milking procedures are carried out, take about 3 minutes to attach 24 clusters (Caria et al., 2013). Anyway, the use of SG

to read the information related to each animal is strongly recommended when a specific activity is required for effective management of the flock.

Table 1. Means and standard deviations of milkers' operating time and number of errors per side (24 stalls) of the milking parlor for animal selection and grouping.

	Work Completion Time (min)	Number of Errors
Total (N = 32)†	11.1 ± 3.70	0.8 ± 1.44

†*sixteen milkers per two milking parlor sides.*

We also measured text comprehension based on the number of reading errors by asking milkers to identify the ewes that had a "yearly milk yield higher than 250 kg". In every case, the errors during the trials were caused by a failure to recognize the information requested. The frequency of failures per side of milking parlor was approximately 3.3%, which did not seem to affect the quality of work. Specifically, the total number of errors was 16 and 11 for graphic and text composition, respectively, which corresponded to 16.6% and 11.5% of all milk yields signed per each of them. The 43.8% of milkers correctly read all the information reported in the QR codes scanned, allowing the recognition of the animals that need to be separated. This is an encouraging result since the operators performed an agricultural task using for the first time a modern device with which they did not have a high level of confidence. Four workers out of nine made errors reading both graphic and text composition files; furthermore, these were responsible for the highest number of errors.

Table 2 summarizes the results for NASA-TLX scores. The statistical analysis has no underlined significant differences on the overall scores or for each categories of the NASA-TLX but we can observe that the perceived workload for the TXT composition type were basically higher (overall workload 40.21 vs. 34.90), as obtained also by Kim, S. et al., (2019) in a study where they compared two different user interface designs in simulated warehouse order picking. In particular, the graphic-based (vs. text-based) information led to decreases of 21.1% for mental demand, 19.7% for temporal demand and 6.4% for physical demand. As a consequence, the graphic-based information type

was more usable by the farmers. These results are also in accordance with the visual dominance theory where visual inputs tend to dominate other modalities in perceptual and memorial reports and speeded responses (Posner et al., 1976). Nonetheless, these low difference percentages may be explained by the human propensity for memorizing the position of the information in the text-based type requested during the experiment.

Table 2. Summary of NASA Task Load Index (NASA-TLX) subscales scores (mean and standard deviation).

	Information composition type	
	Text	Graphic
Mental Demand	47.50 ± 28.75	37.50 ± 29.21
Physical Demand	39.06 ± 32.10	36.56 ± 29.31
Temporal Demand	47.50 ± 28.93	38.13 ± 28.51
Performance	35.00 ± 29.94	33.13 ± 28.63
Effort	32.50 ± 30.39	30.63 ± 31.30
Frustration	24.38 ± 28.45	22.50 ± 27.99

Observing the perceived overall workload for each milker, the text-based information was higher in 75% of milkers than was the graphic-based information (Figure 4). These results confirmed that the arrangement of information influences its receptivity.

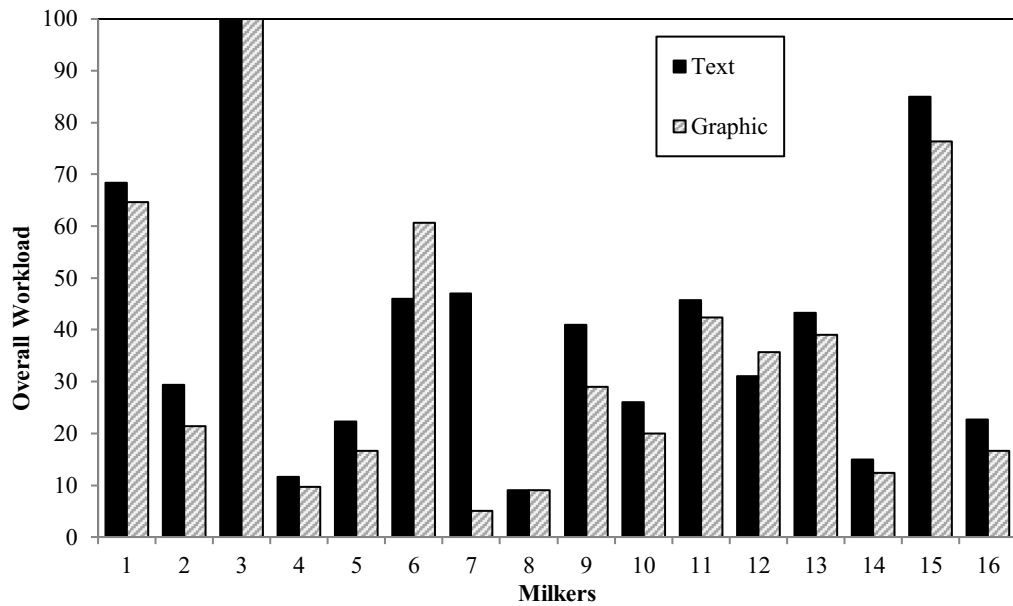


Figure 4. Overall workload by information composition type (text and graphic-based) per milker.

Table 3 summarizes the score of the IBM CSUQ. The mean of each statement and category (SYSUSE, INFOQUAL, ITERQUAL, OVERALL) is reported. Considering the device usefulness category (SYSUSE), for statements four, five and eight, concerning efficiency, speed and productivity to complete the task with the SG, respectively, the participants gave a neutral score (i.e., neither agreed nor disagreed).

Table 3. Mean score for each statement of the modified IBM Computer System Usability Questionnaire (CSUQ). The four categories are reported: System usefulness (SYSUSE), Information quality (INFOQUAL), Interface quality (ITERQUAL), Overall satisfaction (OVERALL).

Category	N [†]	Statement	Mean	SD	Category Mean
SYSUSE	1	Overall, I am satisfied with how easy it is to use this device	4.19	0.98	
	2	It was simple to use the device	4.19	1.17	
	3	I could effectively complete my work using this device	4.00	1.26	
	4	I was able to complete my work quickly using this device	3.69	1.14	
	5	I was able to efficiently complete my work using this device	3.63	0.96	
	6	I felt comfortable using this device	4.06	1.18	
	7	It was easy to learn to use this device	4.69	0.48	
	8	I believe I could become productive quickly using this device	3.44	1.26	3.98
INFOQUAL	9	It was easy to find the information on mastitis I needed	4.69	0.48	
	10	It was easy to find the information on milk production I needed	4.56	0.63	
	11	The information was effective in helping me complete the task and scenarios	4.50	0.63	
	12	The organization of text-format information on the device display was clear	3.56	1.15	
	13	The organization of graphic-format information on the device display was clear	4.06	1.00	4.28
INTER QUAL	14	This device has all the functions and capabilities I expect it to have	3.75	1.06	3.75
OVERALL	15	Overall, I am satisfied with this device	4.38	0.81	4.38

[†]refers to the question numbers

This score was likely related to SG QR code scanning and file opening time since this aspect slowed down the milking procedures. However, the use of SG enabled the completion of the overall task (identification, selection and milking) employing only one worker (statement 3).

The seventh statement suggested that the SG are relatively easy to learn and use; in fact, participants strongly agreed with this statement, receiving the highest score (4.69 ± 0.48). In the information quality section (INFOQUAL), we observed that participants strongly agreed with statements nine and ten regarding the ease of finding the information in the document. Moreover, the milkers agreed that this information is helpful for task completion. As expected, the information in text-format displayed on the SG is less clear than information in graphic-format (statements 12 and 13), in accordance with the results highlighted in the NASA-TLX. Thus, these results confirmed that the graphic composition was more usable by the workers. Specifically, the farmers usually find the information related to the evolution of milk production and body condition score as a graph representation. The overall satisfaction on the usability of the SG was positive, with a mean score of 4.38 ± 0.81 . This suggested that the device is helpful for the identification and selection of the animals during the milking session.

4. Conclusions

This study is the first contribution to improving the knowledge on how AR devices interact with a farm environment, focusing primarily on human perception and usability. We investigated two combinations of content presentation for reading animal information through SG for AR while milking. We examined the overall completion time and failures rate to perform the task, further supporting our survey with subjective data. Results showed that presenting information in text-based format results in a higher workload relative to a graphic-based format. Moreover, the type of augmented visual stimuli presented to the farmers, represents an important aspect that needs to be carefully analyzed in future studies. The overall satisfaction on the usability of the SG has been positive, allowing milkers to properly complete the animal identification and selection

process during milking (approximately 3% of failures). The development of SG with specific features for application in the livestock sector may be relevant to improve the performance of farm activities. The possibility to perform hands-free tasks will allow the reduction of the workforce involved.

Author Contributions: M.C., G.S. and G.T. conceived and designed the experiments, wrote the manuscript and analyzed the data. G.S. and M.P. collected the data. M.C., G.T. and A.P. revised the manuscript. All authors have read and agreed to the published version of the manuscript.

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CHAPTER 6

Smart Glasses' Acceptance by Agricultural Stakeholders Using the Technology Acceptance Model (TAM)

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Abstract

The rapid growth and development of Augmented Reality technologies and smart glasses for augmented reality will bring to a widespread diffusion of these digital devices in many fields of work such as medicine, engineering, and education. Recent studies highlighted that augmented reality could be a useful technology supporting farmers in agricultural activities. This study examines the acceptance level of agricultural stakeholders to use smart glasses for augmented reality in their activities. In order to bridge the gap between agricultural stakeholders and augmented reality devices the factors related to the acceptance of smart glasses were investigated and evaluated through the Technology Acceptance Model (TAM). The modified TAM was used considering its prime construct which includes perceived ease of use (PEOU), perceived usefulness (PU), attitude to use (AT) and intention to use (IU), with the addition of the perceived benefit (PB). The questionnaires were submitted to agricultural stakeholders that had previous knowledge on augmented reality and smart glasses applied to the agricultural sector. The results obtained by the survey's analysis showed that attitude and perceived benefit influenced the agricultural stakeholder's behavior on the acceptance of smart glasses as a possible new tool to support on-farm activities, moreover, indirectly affected by its perceived ease of use.

Keywords: Digital Livestock Farming, Augmented Reality, Structural Equation Modeling, SEM, head-wearable device

1. Introduction

Digital agriculture is a new concept of farm management, consisting in the use of information technologies (hardware, software, database, networks) related to farm's data and production units (field, crops, animals,) to improve management strategies and increase yield per animal or per hectare (CEMA, 2017). Digital agriculture was defined as the use of new and advanced technologies that could be integrated into one system to help farmers to improve food production (Trendov et al., 2019). The use of digital technologies allows to have a Precision Livestock Farming (PLF) approach in the management of the farm, which means that through the support of digital technologies it is possible to improve production (milk and meat yield), animal health status (SCC monitoring, sub-clinic mastitis) and animal-human welfare (thermal stresses, reducing the hour per day in the barn) Halachmi et al., 2019. Some examples for the dairy sector are digital milk meters, GPS collars, ear tags, bolus, cameras monitoring, where the digital technologies have been already commercially implemented (Groher et al., 2020).

The opportunities of the digitalization of the agricultural sector and digital technologies have been stated but there are several barriers to overcome before a wide diffusion and adoption, i.e., farmers' self-sufficiency, rational use of data in driving decision, easy to use devices interface, etc. (Halachmi et al., 2019; Neethirajan and Kemp, 2021).

An emerging device in the digital agricultural context are the augmented reality (AR) headset, otherwise known as, smart glasses (SG). The SG are digital devices, wearable on the user's head. They are usually equipped with a viewer at eyes level where the virtual contents are shown. The virtual projected contents are combined with the real one on the SG display, are registered and aligned with the surrounding environment, and are interactable in real-time by the user through a mobile device (Chatzopoulos et al., 2017; Ro et al., 2018). These are the main characteristics of an AR device, specifically mobile AR devices, which can be also related to smartphones and tablets. The SG for AR have been progressively introduced, especially in the professional context, to affect the effectiveness and quality of the human-machine interaction interface (Szajna et al., 2020). The use of SG as a digital agricultural tool and its possible integration in the farming system was highlighted in some research studies (Huuskonen and Oksanen, 2018; Caria

et al., 2019) but these devices are still in the early stage of development, especially if considered for agricultural and livestock use to support farmers (Caria et al., 2020).

An expected fundamental step to the diffusion and use of digital technologies in agriculture will be related to the intra-communicability between all the smart and PLF technologies available on the farm, such as sensors (collars, pedometers, biometric sensors, etc.), device (computer, mobile tool), machinery (milking robot, mixer wagon), etc. (Bahlo et al., 2019; Neethirajan and Kemp, 2021). The highest potential of SG for AR could be expressed when integrated with other smart farming technologies also via the IoT and cloud services (Phupattanasilp and Tong, 2019). Moreover, the digitalization of the agricultural sector may increase public acceptance owing to the possible improvement of animal welfare and more sustainable production. Nevertheless, these technologies “may also be perceived as a threat” (Pfeiffer et al., 2021).

One important obstacle to overcome is related to the acceptance of these technologies, as a helpful tool, by the agricultural stakeholders. Furthermore, to allow the adoption of digital or PLF technologies in the farming context it is important to understand the conditions and factors that influence its acceptance (Aubert et al., 2012). The factors influencing attitude and use of the innovation technologies could be external (farm size, economic power, etc.) or related to the beliefs of the farmer (Cavallo et al., 2014) or also depends on solving acceptability issues, such as making software easy to use and intuitive data visualization and interaction (Koltès et al., 2019). Moreover, the study by Cavallo et al., (2014) identifies three different attitudes of Italian farmers toward technological innovations: those who reject technological innovation altogether, those who would like to use innovative technologies in the future, and those who already use them. Other factors influencing the diffusion and adoption of digital tools could be related not only to economic conditions but also to cultural characteristics (Petridis et al., 2020).

Many studies were published on the issue of acceptance of technology. Different models were used to investigate the factors related to the rejection or acceptance of information technologies. These models are derived from the Technology Acceptance Model (TAM) developed by (Devis, 1989). The TAM is a framework for modelling the user’s acceptance and use of information systems based on their attitude, perception, and

belief that has prediction and explanation capabilities (Devis et al., 1989). Through the TAM, fundamental latent variables were identified and adapted from previous theory, the Theory of Reasoned Action (Fishbein and Ajzen, 1975). The main TAM's latent variables, that are indirectly measured with the manifest variables, are perceived usefulness and perceived ease of use that should influence the intention to use the technology through the mediation of individual attitude (Marangunic' and Granic', 2015). The perceived usefulness was defined as “the degree at which a possible user believes that using an application system will enhance his or her job performance”, whereas the perceived ease of use was defined as “the degree to which a possible user believes that the use of application system will be free of effort” (Devis et al., 1989). The TAM was extensively used during the years to measure the intention to use a wide range of information technologies such as e-mails, operating systems, databases (Legris et al., 2003), telemedicine services (Kamal et al., 2020), and even smart wearables like watches, sensors, and glasses. In fact, it was underlined that TAM was the most used theory in smart wearables' studies (Niknejad et al., 2020). The TAM framework was also applied to predict the usage intention of innovation technologies, or even innovative and sustainable management systems in the agricultural domain (Naspetti et al., 2017; Caffaro et al., 2020; Rezaei et al., 2020). Other examples in the farming context are related to the acceptance of drones (Michels et al., 2021), artificial intelligence (Mohr and Kühn, 2021), and smart farming technologies (Adrian et al., 2005; Caffaro et al., 2020) by the farmers. The factors that influence the adoption or intention to use SG by consumers were studied by several authors (Rauschnabel and Ro, 2016; Basoglu et al., 2017; Kalantari and Rauschnabel, 2018), while on the other hand, the adoption intention by professional users and what factors affect it have been studied less. In addition, Rauschnabel and Ro, 2016 underline how TAM represents a preliminary point in investigating the factors that affect SG for AR in the first stage of development.

In this way, in the study, the original TAM was used with the addition of one external variable. Thus, the intention to use SG in a livestock farming context was related to the attitude toward its use, perceived usefulness, and perceived ease of use. Moreover, the intention to use SG was related to perceived benefit defined as “the belief that the

technology will provide benefit of greater value than its cost” and therefore evaluating the possible advantages in using SG in a farm but taking into consideration the economic cost of purchase and implementation (Adrian et al., 2005).

The work aimed to bridge the gap between an AR device, specifically SG, and agricultural stakeholders investigating the acceptance of this new technology from the agricultural sciences students, and which factors could affect the intention to use SG, in the farming environment, through the TAM instrument.

2. Materials and Methods

2.1. TAM framework and Hypothesis development

Figure 1 shows the model proposed for the study, which is a slightly modified version of the original TAM. The model reports all the constructs considered for the study. As the endpoint of the model has been considered the intention to use (IU) SG by agricultural stakeholders and not the actual use of the system as the SG are not yet widespread and used by farmers. The diagram also shows the relationship between the constructs represented by the arrows. It was hypothesized that IU of SG was influenced by the attitude toward its use (AT) as “an individual’s positive or negative feeling about performing the targeted behavior” (Fishbein and Ajzen, 1975), and by the perceived benefit (PB). Finally, the AT and PB constructs mediate between the IU and the perceived usefulness (PU) and perceived ease of use (PEOU).

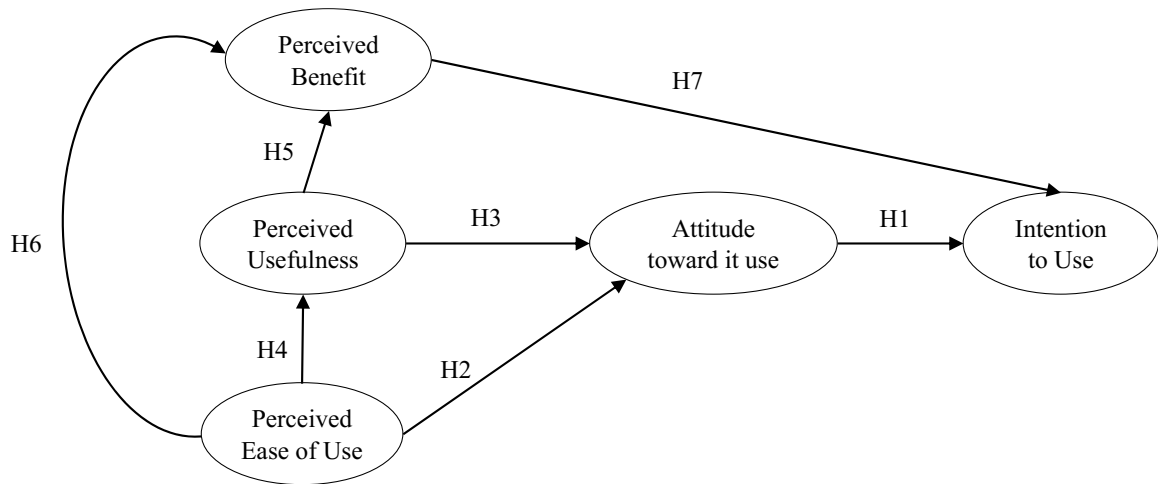


Figure 1: Proposed structural model for the study and hypothesis to test.

Based on the findings, reported in the first section of the manuscript, on the TAM studies for the agricultural and SG domain the following hypothesis were formulated:

- H1.** Attitude toward the use of smart glasses (AT) will positively affect the intention to use (IU) smart glasses by agricultural stakeholders.
- H2.** Perceived ease of use (PEOU) will positively affect attitude toward using smart glasses (AT) by agricultural stakeholders.
- H3.** Perceived usefulness (PU) will positively affect attitude toward using the smart glasses (AT) by agricultural stakeholders.
- H4.** Perceived ease of use (PEOU) will positively affect the perceived usefulness (PU) of using smart glasses by agricultural stakeholders.
- H5.** Perceived usefulness (PU) will positively affect the perceived benefit (PB) of using smart glasses by agricultural stakeholders.
- H6.** Perceived ease of use (PEOU) will positively affect the perceived benefit (PB) of using smart glasses by agricultural stakeholders.
- H7.** Perceived benefit (PB) will positively affect the intention to use (IU) smart glasses by agricultural stakeholders.

2.2. Research instrument and participants

For this study a survey was developed to measure the five constructs of the TAM considered, which, being latent, cannot be measured directly. Each latent variable was measured with multiple items or manifest variables (Table 1) using a 5-point Likert scale which answers choices were: 1. strongly disagree; 2. disagree; 3. neutral; 4. agree; 5. strongly agree. To measure each construct was used a minimum of three items (Schumacker and Lomax, 2010). All the items considered in this study were adjusted from previous surveys to match with the farming context. The PU and PEOU items derived from Devis, 1989; Devis et al., 1989. AT items derived from Fishbein and Ajzen, 1975, PB items derived from Adrian et al., 2005, and IU items derived from Venkatesh et al., 2008 and Cabero-Almenara et al., 2019.

The questionnaire was submitted via e-mail to university students of the Agricultural Sciences Department. The students were selected for the survey as people related to the agricultural domain and as a surrogate for professionals (King and He, 2006). Moreover, the target students involved in this study followed courses on AR and SG applied to the farming context, and livestock farming engineering and mechanization, who were most aware of SG and its possible application in agriculture. The questionnaire was originally developed in English and then translated in Italian (respondents' mother tongue) in order to submit to the students. A total of 162 students were involved, of which 40.1 % answered. Of the total respondents, 58.4 % are male. The average age was 25 years old. The level of degree of the respondents was 9.2 % master, 23.1 % bachelor, 67.7 %, not yet graduated but registered in the bachelor course.

Table 1. Items (manifest variables) used in the survey submitted to agricultural stakeholders.

Construct	Item	Measurement item
Perceived Benefit	PB1	I believe using SG for farm management (data and report visualization on the field) could increase farm profit.

	PB2	I believe SG are cost-effectively related to the possible applications in the agricultural sector.
	PB3	I believe SG can reduce costs.
Perceived Usefulness	PU1	Using SG in an on-farm job would enable me to accomplish agricultural tasks more quickly (e.g., feed selection, feed preparation, animal identification).
	PU2	Using SG would improve my on-farm performance thank to the information overlayed in real-time.
	PU3	Using SG during my on-farm job would increase productivity (crop or livestock precision management).
	PU4	I would find SG useful as a farm technician/owner.
Perceived Ease of Use	PEOU1	Learning to use SG (Interaction with the system, starting app, digital content visualization) will be easy for me.
	PEOU2	It would be easy for me to get SG to do what I want it to do.
	PEOU3	My interaction with SG will be clear and understandable.
	PEOU4	It would be easy for me to become skillful at using SG to manage the farm information.
Attitude toward its use	AT1	Using SG as an auxiliary system for the farm's data visualization and management will be a good idea.
	AT2	Using SG as an auxiliary system for the farm's data visualization and management will be a wise idea.
	AT3	Using SG as an auxiliary system for farm's data visualization and management will be beneficial.
Intention to Use	IU1	In the future, I would like to use SG to manage more precisely the farm as owner or technician.
	IU2	In the future, I intend to use SG to manage more precisely the farm as owner or technician.
	IU3	In the future, I predict to use SG to manage more precisely the farm as owner or technician.

2.3. Statistical data analysis

The students' answers to the questionnaire and the relationships hypothesized in the TAM were analyzed using the structural equation modelling (SEM) technique, through the lavaan package available in the R software (Rosseel, 2012). The version of R used was 4.0.5.

The model was analyzed using a two-step approach (Anderson and Gerbing, 1988). Firstly, the measurement model was examined performing a confirmatory factor analysis (CFA) to test the quality and suitability of the model (convergent and discriminant validity, model fit). Then the structural model, using maximum likelihood (ML) estimation, was evaluated assessing the relationship among the constructs to test the formulated hypothesis. To test the overall model fit four indices were used: comparative fit index (CFI); Tucker-Lewis index (TLI); the root mean square error of approximation (RMSEA); and the standardized root mean square residual (SRMR).

3. Results

3.1. Measurement model analysis

The first step was to test the measurement model to assess the relationship between the observed variables (manifest/items) and the underlying latent variables (construct). Despite the ML estimation method “is robust to moderate violation of the normality assumption” (Anderson and Gerbing, 1984), the normality of the data was assessed computing skewness and kurtosis index, that respect the threshold for the normal data distribution (Weston and Gore, 2006).

Next, confirmatory factor analysis (CFA) was performed to test the measurement model and determine constructs' validity assessing convergent and discriminant validity. Specifically, to evaluate constructs' validity, standardized factor loading, average variance extracted (AVE), and composite reliability (CR) were considered (Lee et al., 2019). The discriminant validity was checked comparing the square root of AVE with the corresponding constructs' correlations (Fornell and Larcker, 1981). The model fit was assessed using four fit indices; comparative fit index (CFI), the Tucker-Lewis index

(TLI), the root mean square error of approximation (RMSEA) and the standardized root mean square residual (SRMR).

Despite the hypothesized model showed satisfactory convergent validity and the fit indices were over the recommended threshold, a discriminant validity issue was observed. Specifically, the construct PU results highly correlated with AT and PB not satisfying the discriminant validity request. Due to this issue, the PU construct was removed from the model. Then for the model without PU variable was again performed CFA.

The results on the new measurement model analysis and the descriptive statistics are reported in Table 2. The mean value for the overall constructs was 3.86, which indicate that on average, respondents perceived SG device positively. Considering the convergent validity all factor loadings are greater than the minimum value of 0.6 (Anderson and Gerbing, 1988), confirming a high correlation between items predicting the corresponding construct. Moreover, the average variance extracted (AVE) and composite reliability (CR) of each construct were more than 0.5 and 0.7 respectively (Fornell and Larcker, 1981; Nunnally and Bernstein 1994) further confirming satisfactory convergent validity and internal consistency. In Table 3 are stated the discriminant validity results showing good validity for all constructs considered in the updated model, without PU construct.

Table 2. Confirmatory Factor Analysis for the measurement model with the loadings for the items. Descriptive statistics with mean and standard deviation (SD) are reported for each item. The computed average variance extracted (AVE) and composite reliability (CR) are reported for each construct.

Construct	Item	Mean	SD	Std. Loadings	AVE	CR
Perceived Benefit (PB)	PB1	3.57	1.05	0.796	0.560	0.792
	PB2	3.35	0.96	0.676		
	PB3	3.31	1.00	0.768		
Perceived Ease of Use (PEOU)	PEOU1	4.09	0.88	0.782	0.681	0.894
	PEOU2	3.77	0.96	0.917		
	PEOU3	3.85	0.94	0.853		
	PEOU4	3.66	0.87	0.737		
Attitude toward using (AT)	AT1	4.26	0.73	0.805	0.663	0.854
	AT2	4.11	0.85	0.738		
	AT3	4.15	0.87	0.892		
Intention to Use (IU)	IU1	4.25	0.79	0.919	0.756	0.902
	IU2	4.20	0.85	0.927		
	IU3	3.66	0.99	0.752		

Table 3. Discriminant validity result. Diagonal bold numbers are the square root of the average variance extracted.

	IU	AT	PEOU	PB
IU	0.870			
AT	0.814	0.814		
PEOU	0.666	0.699	0.825	
PB	0.656	0.649	0.388	0.748

3.2. Structural model analysis

The full structural model analysis allows to investigate the relationship among latent variables (constructs) of the model, estimating expected directional associations among variables. The results of the analysis of the relationship between the constructs are reported in Figure 2, furthermore, showing the standardized parameter estimates for the path coefficients and the statistical significance of each hypothesized path. The overall model fit was evaluated using several indices: comparative fit index (CFI), the Tucker-Lewis index (TLI), the root mean square error of approximation (RMSEA) and the standardized root mean square residual (SRMR). The CFI and TLI were higher than the recommended value of 0.9, respectively 0.976 and 0.969. The RMSEA and SRMR were lower than the recommended value of 0.1 respectively 0.058 and 0.061. Therefore, the overall model fit is acceptable (Bagozzi and Yi, 1988; Bentler, 1990; Cheung and Rensvold, 2002).

All the relationships tested were statistically significant at $P < 0.001$ (Figure 2). It was not possible to test hypothesis 3, 4, and 5 due to the dropping of PU construct. Considering the other validated constructs was observed that the intention to use (IU) SG by agricultural stakeholders was affected from the attitude toward its use (AT) and perceived benefit (PB), supporting H1 ($AT \rightarrow IU$) and H7 ($PB \rightarrow IU$) respectively. Furthermore, H2 ($PEOU \rightarrow AT$) and H6 ($PEOU \rightarrow PB$) were supported, indicating that perceived ease of use (PEOU) affected attitude in the use of SG, with the largest effect (0.731), and the perceived benefit.

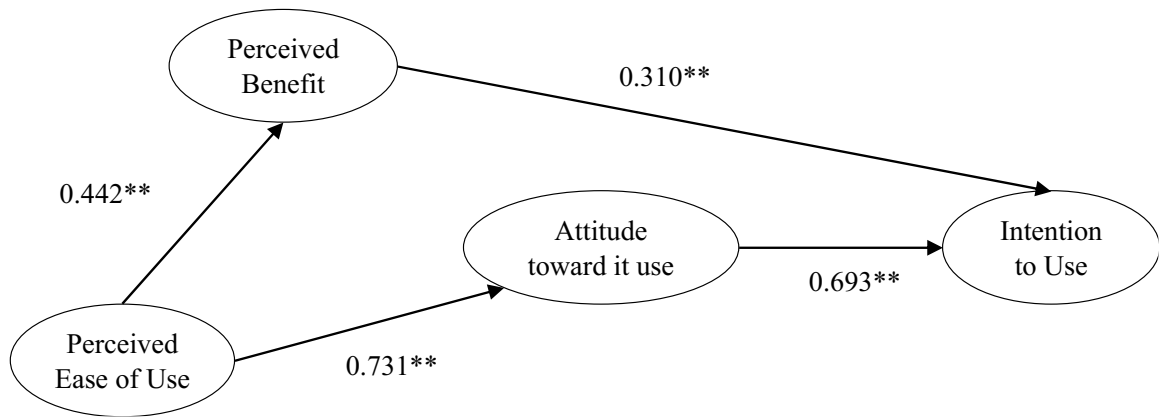


Figure 2. Final modified structural model of the TAM. Standardized parameter estimates for path coefficients are reported (** significant at P value < 0.001).

4. Discussion

The aim of the study was to investigate, through the TAM instrument, which factors affect the use intention of a new digital device in the livestock farming domain, as SG. The TAM model was used for its relevance in the investigation of AR and SG acceptance (Ibili et al., 2019; Niknejad et al., 2020), and its application also to the technology acceptance in the agricultural context (Sharifzadeh et al., 2017). The original TAM was extended with the perceived benefit (PB) construct, directly related to the intention to use (IU).

As showed in the results section, the intention to adopt SG by the university agricultural students, as a future owner/technician in the farming and livestock farming contexts, is positively influenced by their attitude toward the use of this digital device. This result is in line with TAM theory findings, moreover attitude appeared to be a satisfactory predictor of behavior at the early stages of technology adoption, as in the case of this study. Thus, agricultural stakeholders with a positive attitude toward its use will be more intentioned to adopt SG in on-farm activities, to manage crop or livestock precisely, e.g., visualizing in real-time data and reports in AR, for feed selection, feed preparation, animal identification, etc.

In turn, it has been pointed out that attitude was influenced by perceived ease of use, thus, the more SG are perceived as simple to use, the greater will be the attitude of farmers toward this technology. In this way the attitude mediated the influence of the ease of use on the intention to use SG, interpreting this path as an indirect strong effect of ease of use on the intention.

Furthermore, the perceived ease of use SG was observed as a predictor of the perceived benefit. Hence, the more the SG will be ease to use the more the benefit of its integration in the farm activates will perceived. The perceived benefit, as attitude, mediate the influence of ease of use on intention. In fact, was observed that perceived benefit had a direct effect on the intention to use SG, as underlined by a previous study (Adrian et al., 2005) where the perceived benefit was a significant determinant of intention. This result underline that agricultural stakeholders may be willing to use SG despite the price, as the benefit of using SG outweighs the perceived cost. Finally, considering the path coefficients among variables, that as they are standardized can be compared, was observed that the attitude was more important than perceived benefit in predicting the intention to adopt the SG in the agricultural domain.

5. Conclusions

To the best of our knowledge, this is the first study that applied TAM to investigate the factors leading to the acceptance and intention to use smart glasses by agricultural stakeholders. In particular, the TAM survey was submitted to agricultural university students as a surrogate for professionals. This study supports the reliability of the TAM framework in explaining technology adoption intentions also applied in a digital livestock farming context. In this way, the intention to use smart glasses, on the farm was directly affected by the attitude and perceived benefit, and indirectly by the perceived ease of use. Hence, the agricultural stakeholders will be willing to use smart glasses the more positive their attitude and the greater the perceived benefit, in turn, influenced by their ease to use. It was not possible to test the perceived usefulness paths since results highly correlated with the attitude and the perceived benefit. Despite the items in predicting the perceived

usefulness resulted good (high factor loading) in future studies different items should be used to determine and validate perceived usefulness as a main construct of TAM, moreover, other external variables should be considered to expand the model and improve the knowledge on the farmers' intention to use smart glasses.

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CHAPTER 7

General Conclusions

Concluding Remarks

The general aim of this thesis was to explore emerging digital technology, as smart glasses (SG) for augmented reality (AR), integrated in the livestock domain. Different professional SGs, available in the market, were tested considering the operating performances and technical features of the devices. In addition, the agricultural stakeholders' points of view were taken into account evaluating their capabilities, attitudes, and perceptions toward the use of SG for agricultural purposes.

The scientific literature reported a limited availability of studies on AR and SG in the agricultural sector, and any scientific work for the livestock sector was found. For this reason, the first experimental contributions of the thesis focused on the preliminary investigation of a SG in a farming context, studying the functionality and performances of the AR headset device. In particular, the first experimental work (Chapter 2) focused on the performances' evaluation of the GlassUp F4 SG, to prove how this device could be a valuable tool for livestock farms. Thanks to laboratory and on-field tests, the capabilities of SG to achieve augmented information overlaid on farm objects (e.g., animals, feedstocks, machineries) were explored. The study highlighted also how video-sharing represents a worthy tool for remote assistance in real-time and hands-free. This first study showed the great potential of SG in agricultural farms, ranging from single subject identification, photo and video acquisition to hand-free calling, and remote assistance.

In the second experimental contribution (Chapter 3) different SG (Vuzix M400) were tested according to their structural and technical characteristics. In addition to performances tests, the voice control functions were investigated considering common noise conditions in the livestock farm (barn, milking room, tractor). An AR assistance scenario for the milking machine check was moreover developed through a cloud service application. Thanks to the markers' detection, positioned in different points of the farm (machineries, facilities, etc.) it was possible to obtain precise augmented contents in real-time. The AR system allowed to get a guided workflow for the maintenance of the milking machine and to check the working principles of the system (pulsation characteristics, vacuum level). This specific device could be completely managed hands-free thanks to

the voice control function. However, the maximum noise level to vocally commands the SG was of 70-75 dB.

In the fourth chapter different types of SGs for AR were compared evaluating the technical advantages of their integration in agricultural systems. Three SGs with optical or video visualization systems were adopted since in the last decade SG with different characteristics, e.g., display types, interaction methods, and features, have been developed. These aspects may affect the AR headset experience, leading to different performance levels and integration on farms. Due to the heterogeneity of the devices the SGs could be integrated in the agricultural tasks, in function of their characteristics (marker detection, audio-video transmission, field of view, weight, etc.).

After the general evaluation of SGs in the agricultural context, the next experimental contribution (Chapter 5) directly involved the farmers to evaluate both the performances and the users' perceptions of the device. Based on laboratory preliminary tests (Chapter 2), a specific trial was set up to evaluate the usability level of SG and the cognitive workload required for the identification and selection of animals during a milking session. In this study, the SG were used by the farmer to visualize specific information of the animal in order to select the most productive subjects. The farmers resulted overall satisfied using SG, suggesting that the device can represent a valid support during milking.

The last experimental contribution focused on the acceptance level of agricultural stakeholders to use SG for AR in their activities (Chapter 6). The factors related to the intention to use SG were investigated and evaluated through the Technology Acceptance Model (TAM). The variables considered in the model were "perceived ease of use", "perceived usefulness", "perceived benefit", "attitude toward the use" of SG, and "intention to use" SG in agricultural activities. The magnitude and the relationship between the variables were investigated using the structural equation modeling (SEM). The results obtained by the survey's analysis showed that attitude and perceived benefit influenced the agricultural stakeholder's behavior on the acceptance of SG as a new tool to support on-farm activities. The variable of intention to use was indirectly affected by the perceived ease of use. Thus, the greater attitude of farmers for the use of SG the higher

will be their intention to use that specific technology. Finally, farmers will be interested to use SG that are easy to use, considering its interface, interaction systems, contents visualization, etc. Therefore, the development of wearable systems for AR should be intuitive and easy to use, to facilitate their spread in the agricultural and livestock sector.

Future Prospective Works

The spread of digital technologies in the agricultural sector has been underestimated for several years, but it can guide farmers in a new phase of change and revolution of the production processes with the aim of increasing a sustainable productivity. The decision processes within the farms will be based not only on the experience of the farmer but also on the large amount of data collected by sensors and automatically analyzed, to guide and inform the farmer.

The digital technologies are developed and studied for many professional domains, and then integrated also in agriculture. Similarly, the SG technology for AR have been extensively studied and applied in industry, logistics, education, and they could be included in the agricultural sphere.

In order to support the integration of SG in the agricultural domain, a greater stakeholder engagement is necessary. The specific contribution and involvement of farmers during the development and test of specific devices devoted for agricultural purposes is strongly recommended. Further evaluations of the operator's perception of the quality of digital information viewing on SG might be done, considering technical aspects (field of view, visualization system, etc.)

These aspects will concern evaluations of mixed reality devices such as HoloLens 2, with a higher level of complexity and with a likely higher computational capacity than the devices used for the current experimental activities. Adopting and testing this promising device could help to overcome the issues found in this research work mainly linked to the integration of SG in the farms.

Furthermore, successive research steps may include the development of more complex and interconnected livestock farm systems that integrate PLF technologies (animal EID, milking robot, sensors) and AR devices. This will improve the precise and

punctual management of farm data. Another valuable aspect is related to the big data processing and simplification to provide farmers with useful information in a user-friendly interface. Future improvements would be also related with sensor-based (GPS, RFID, etc.) AR solutions to extend the use of this technology also in extensive farms to provide real time data in the open field. Future challenges will aim to enlarge infrastructural coverage of internet networks in rural areas, which represents the basis to the adoption of these digital technologies.

SARS CoV-2 virus limited many activates of this PhD work, but an important result was however achieved about the necessity to improve SGs in an integrated PLF system for more efficient and sustainable livestock farm.