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Augmented Reality Smart Glasses for Industry: How to Choose the Right Glasses

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Abstract. Augmented reality smart glasses (ARSG) have been available as a commercial product since 2015. Many potential usage areas have been identified, including industrial use. The needs from industry have evolved, with more emphasis being put on sustainability. While ARSG can help improve efficiency and sustainability, there are also similarly associated costs to their implementation and use. This paper aims to present a process for how to choose ARSG for specific use cases as assembly operator support while considering the sustainability of their implementation. A narrative review of the literature was made to identify the current understanding of the environmental impact of ARSG, as well as what has been considered in regards to ARSG being integrated into a manufacturing environment. The analysis of the literature resulted in a proposed decision process. The decision process serves as a baseline for how to guide the decision of whether ARSG could be a suitable solution and, if so, what aspects to consider in the choosing of the ARSG model. Future work includes collaboration with industry to further improve the decision process based on empirical input.

Keywords. Augmented reality smart glasses, operator support, cyber-physical systems, smart production, sustainability

1. Introduction

Augmented reality smart glasses (ARSG) have become a technology that is utilized in many different fields, as well as an area of increased research interest [1]. The utilized fields include the manufacturing industry and, more specifically, assembly guidance [2].

There have been previous studies on what to consider when choosing ARSG, for instance [3] mapped the then publicly available ARSG and provided a process for how to evaluate ARSG as assembly operator support. But since then the ARSG market has changed, with new developers and more variations in technical capabilities [4]. The market has also continued to grow and is expected to continue to do so. Estimations vary, by 2030 ARSG have been projected to grow at a compound annual growth rate (CAGR) of about 40 % from 2023 to 2030 [5]. Another estimation is that ARSG will go from 0.54 million units sold 2022 to 7.55 million units sold by 2027, equal to approximately 69 % CAGR [6]. While predictions seem to vary, the historical data and general trend indicates

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a continual growth, although the exact rate is hard to estimate. Previous studies have also found that research on the topic of ARSG is increasing over time [7,8].

Since the main focus for a company is to be profitable and generate sustainable value for its stakeholders, they must work with sustainable manufacturing principles, such as 6R (Reduce, Reuse, Recycle, Recover, Redesign, and Remanufacturing) [9].

The current relevance of ARSG as assembly operator support and the continued positive market development creates a need for understanding the ARSG market from the perspective of applying them for operator support. The ability of ARSG to provide a more efficient production system is also relevant for companies to reach their sustainability goals. But at the same time sustainability is becoming a higher priority for many companies. The aim of this paper is therefore to provide practical guidance in how to choose and integrate a suitable model of ARSG as assembly operator support in a sustainable way, while also considering how the integration can improve sustainability in manufacturing.

2. Research method

The theoretical data collection in this paper has been gathered through the use of the narrative review method [10]. A narrative review lacks the replicability of a systematic review, but can still provide value in presenting theory or frames of thought in regards to the literature in a topic [10]. While there are arguments for systematic reviews having higher quality, less bias, and being more comprehensive than other types of reviews, narrative reviews can still be suitable for some types of topics [11]. When the studies being reviewed are of quantitative studies with diverse methodologies, or if different theoretical conceptualizations, constructs, and/or relationships have been examined, then a narrative review would be appropriate to analyze the data [12]. To help support the creation of better narrative reviews, a scale for assessing narrative reviews has been proposed [13].

3. Background

This section provides a theoretical introduction to the central concepts of this paper: augmented reality (AR) and sustainability, as well as their interrelationship.

3.1. Augmented reality

The term “augmented reality”, possibly first used by [14], has since become an area of great research interest. It is defined as to combine real and virtual objects in a real environment, run interactively in real time, and to align real and virtual objects with each other [15]. AR can be implemented spatially, as a handheld device or worn on the user’s head [16,17]. In this paper the focus is on AR implemented as a head worn device in the form of ARSG. The definition that is used for ARSG in this paper is *“a wearable device with one or two screens in front of the user’s eyes that can merge virtual information with physical information in the user’s field of view (FOV)”* [18 p. 1299]. Besides screens, ARSG are also equipped with various sensors to understand and interact with the surrounding environment. These sensors include cameras, accelerometers, gyroscopes, and sometimes even depth sensors. The cameras capture images and video of the real world, and this data is used to track the user's head movement and understand the environment. The ARSG have a built-in processing unit (often a miniaturized computer or system-on-a-chip) that handles the computation required for tracking the head movement, recognizing objects and surfaces, and rendering digital content. This unit runs the AR software and processes data from the sensors in real-time.

3.2. Sustainability

According to the United Nations Brundtland Commission, 1987, sustainability has been defined as development that *"meets the needs of the present without compromising the ability of future generations to meet their own needs"* [19 p. 16]. Three pillars, environment, society, and economy should be considered when implementing sustainability [20].

To reach sustainable production systems, some actions should be considered, like negative environmental impact reduction, improving the efficiency of energy and resources, generating a minimum amount of waste, providing safety in operation, improving personal health, and improving and maintaining the quality of the relevant product and process [9].

In order to solve the mentioned issues and reach sustainability, it is very important to design a production system that prioritizes environmental protection, resource efficiency, and waste reduction, according to [21]. They further describe the intention of sustainable production systems in the following manner: "Sustainable production systems are intended to promote sustainable development by ensuring that the needs of the present are met without jeopardizing future generations' ability to meet their own needs" [21 p. 1]. The goal of these systems is to preserve natural resources and to reduce the negative impacts of the production process on the environment while encouraging social and environmental development [21].

4. Previous work

In relation to integrating ARSG as operator support within industry in a way that improves productivity and sustainability, the following aspects needs to be considered, both in their own perspectives and in relation to each other; ARSG integration and sustainability. The ARSG integration aspect pertains to what needs to be practically considered to make the ARSG function and provide value in production over time. The sustainability aspect pertains to what the challenges are for the manufacturing industry in improving their sustainability. The two aspects combined pertains to how ARSG integration both can be attained in a sustainable way and how ARSG can contribute to increasing sustainability.

4.1. ARSG integration

As previously described, ARSG for industrial application is an area that has seen an increasing amount of research activity. A comprehensive discussion on ARSG in manufacturing from a holistic perspective is provided by [8]. Among their findings they identified that there is a lack of ergonomic studies of ARSG. Furthermore, tracking was identified as central issue, and four requirements for ARSG deployment in industrial environments were defined: tracking accuracy, tracking rapidity, tracking range, and tracking robustness [8]. And while technological aspects are important, organizational issues haven been found to be even more relevant [22]. Before considering what ARSG to buy, a suitable first step could be to identify the cases where ARSG can feasibly add value [23,24].

4.2. Sustainability in the manufacturing industry

Digitalization in manufacturing has both negative and positive impacts on environmental sustainability (ES) [25]. The main positive aspect found by [25] is the increasing efficiency of using both resources and information. But they also found a primary negative aspect in the increased usage of resources and energy, as well as increasing waste and emission from the life cycle of the increased use of technology hardware. It is therefore recommended to make a complete life cycle assessment, considering the life cycles of both the main product and the supporting technologies and their environmental impacts. In regards to AR life cycle analysis (LCA), it has been found, when doing an LCA on a type of ARSG, the Hololens 2, that the highest energy consumption comes from the use phase and that climate change is the most relevant impact category [26].

4.3. Sustainable AR

While both of the concepts of AR and sustainability are substantially researched, the concept of AR related to sustainability is a research area that is still unfocused [27]. It was further found by [27] in their study that there is no clear understanding of how AR best can be utilized in regards to ES. There is a lack of sufficient empirical evidence on how AR can benefit ES beyond learning [28]. It is believed that AR will support the digitalization of the remanufacturing industry which can further automate this industry [29]. For example, ARSG can provide step-by-step visual instructions for disassembling and reassembling products. The glasses can assist technicians in performing quality control checks and inspections by highlighting areas of interest and flagging defects or discrepancies in real time. This can lead to improved quality and consistency, reducing the likelihood of errors during the disassembly and increasing the material reusage. ARSG can also display real-time data, schematics, and documentation, making it easier for remanufacturers to access critical information. This includes maintenance manuals, part numbers, and quality control procedures, reducing the need for physical paperwork and increasing the possibility to recycle parts of the product being disassembled.

5. Things to consider for ARSG

Before making any larger purchases of ARSG, there are some things to consider. A first step should be to determine what problem the ARSG should solve. There are then two main considerations: technical considerations and sustainability considerations.

5.1. Technical considerations

The first consideration we present is the technical considerations. There are others who have evaluated ARSG as operator support from a more technical perspective. Table 1 presents an overview of aspects from previous studies that are relevant for their suitability as operator support. A short description also summarizes the different aspects. As can be seen, the most common aspects that have been brought up are FOV, interactivity, battery life, weight, weight distribution, durability against dust and water, tracking and ergonomics.

Table 1. Aspects that have been found relevant for ARSG in previous evaluations.

Aspects	Description
Interactivity [3,8,30,31]	How the ARSG can be interacted with. For instance, voice control, gesture recognition, or hardware controls.
Framerate [30]	How fast the system can update renderings, especially when rendering detailed instructions.
Authoring [4]	The ease at which new AR content can be created for the ARSG.
Weight distribution [18,30]	How the weight is spread and the impact it has on the user.
Price [3]	The cost per unit.
Powering [3]	If the ARSG are powered by battery or an external computer.
FOV [3,4,18,31]	How large part of the user's vision the AR-active part takes up.
Battery life [3,4,31]	How long the batteries will last for the intended use. Referred to as powering by [31].
Optics [3]	If the ARSG are implemented through Optical see-through or Video-based solutions.
Camera [3]	How high the resolution of the ARSG camera(s) are.
Open API [3]	Support for third party development, which allows for more content customization.
Audio [3]	Support for both hearing and speaking.
Sensors [3]	Sensors apart from camera that records information about the physical world around the ARSG.
Processors [3]	How fast the ARSG can do computations to allow for real time operation.
Storage [3]	How much memory storage the ARSG have for content.
Memory [3]	How large the work memory is.
Connectivity [3]	How the ARSG can connect wirelessly to update and communicate.
Operating system [3]	The platform on which the ARSG are based on.
Durable against dust [3,31]	How well the ARSG can handle dusty environments.
Durable against water [3,31]	How well the ARSG can handle moisty environments.
Aesthetic look [31]	The visual design of the ARSG.
Compatibility [31]	That the ARSG work seamlessly with other technologies.
Compactness [31]	How much physical space the ARSG take.
Data security [31]	How safe it is to transfer data.
Design frame [31]	How well the ARSG can be customized to different operator head sizes.
Durability [31]	How well the ARSG can withstand damage from continued use.
Ergonomics [8,31]	General challenges related to ergonomic strain on users.

Hands-free [31]	That the user can focus their hand usage on their main task.
Privacy [31]	How safe the information exchange between ARSG and other systems is.
Reliability [31]	How well the different components of the ARSG work together.
Weight [18,31]	The total weight of the ARSG.
Tracking [4,8]	How well the AR content can be positioned relative to the real world.

5.2. Sustainability considerations

The second consideration presented here is that of sustainability. Given the increased demands put on industry in regards to sustainability, this is becoming increasingly important to consider. As previously described, there are three aspects of sustainability to consider: environment, society, and economy.

For the environmental aspect it should be considered how ARSG can help reduce the use of natural resources [32]. Related to reduction, ARSG can avoid quality rejects and keep up the intended efficient performance of equipment [33]. Visualizing data, such as thermal imaging, can identify heat sources or leakages, thereby facilitating energy effectivizations [33].

In regards to the societal aspect, ARSG can make manufacturing safer by reducing physical interaction between humans and machinery, promote collaborative tasks and human-machine interactions, and provide user experiences for training, maintenance, and operational activities [32].

Since reducing the needs for resources can be beneficial both for the environment and the economy, some considerations in the environmental aspect are also relevant for the economical aspect. It should also be considered that an ARSG solution comes with a cost. Specifically, it should be considered that an ARSG based decision support system will introduce costs for set up and operation [33]. These costs need to be considered in relation to the estimated gains from increased efficiency [33].

5.3. A proposed decision process

Based on the diversity of different aspects presented in Table 1, it is clear that there can be several reasonably relevant aspects to consider when buying ARSG. We here present a general recommended process, comprised of eight steps, based on previously identified work. But due to the uniqueness of all different cases, we recommend that the process is rebalanced based on what is the most important in the chosen case to evaluate.

The first step is to identify the use case, where should the ARSG be used and for what purpose? Are there perhaps alternative solutions that could be more suitable in the specific case? It is here important consider as many aspects as possible, such as possible environmental and economic gains as well as costs. If, for instance, an assembly station has two variants of a product that only differs with a few assembly parts that are assembled similarly, a pick by light system could be more cost effective, easier to maintain, and have a smaller environmental impact.

The second step is to consider how the ARSG should be integrated and maintained within the production. As changes in production are made, the ARSG need to be adjustable and updateable just like all other production equipment. An example is that the operating system used on the ARSG can limit their interoperability with other equipment and could create dependencies on specific ARSG-suppliers. While ARSG could potentially reduce need for paper instructions, they could also increase overall energy consumption of the production.

The third step is to plan the scale, how many workstations and operators will be affected, and how many ARSG will be needed? It is recommended to test as early as possible and in a smaller scale to ensure that there is empirical support that the ARSG solution is feasible before a large-scale investment is made.

The fourth step is to search the current market for ARSG that can potentially solve the needs in the chosen case. Given the continued and fast technological development in the ARSG market, it is recommended to do a thorough search for available ARSG with a focus on recent developments. It is better at this stage to be inclusive when considering a model of ARSG.

The fifth step is to rank the identified ARSG based on how well they fit the needs in the chosen case. Based on how common aspects of ARSG have been in previously identified publications, we propose the following set of default aspects to consider. FOV and interactivity are the two most common aspects previously identified. For cases with complex and often updated assemblies, a large FOV might better visually present the task. Interactivity is likely most relevant to guide in complex assemblies, to be able to navigate the instructions with minimal disturbance. Weight, weight distribution, and ergonomics are all closely related and should be seen as a general aspect of ergonomics. Existing regulations related to worn equipment, such as hard-hats, glasses, and similar, could serve as a base line, but specific regulations for ARSG will likely be needed. Battery life should also be considered. How these aspects should be weighed against each other will be very case dependent and they can affect each other. Longer or shorter battery life might come at the cost of heavier ARSG or less functionality, for example.

In regards to sustainability, in the fifth step it is recommended to do a life cycle analysis of the highest ranked ARSG. Can spare parts be bought for the ARSG, or do they need to be fully replaced on damage? Are batteries replaceable? Other aspects, such as FOV and interactivity, might come at the cost of increased energy consumption, increasing environmental impact and operation costs. Consider what functionality is actually needed for the use case and take into consideration that more functionality likely come at the cost in energy, ARSG weight, and complexity.

The sixth step is to buy a minimum viable amount of ARSG to test their suitability for the case. If there are is not one clearly superior alternative, multiple alternative ARSG should be considered. It might be enough with one pair of ARSG of each type, especially in a first evaluation. Operators can experience the ergonomic changes to their work environment and first evaluations on the information presentation can be compared with alternative solutions or ARSG. Before proceeding to the next step, the case feasibility and projected value addition should be thoroughly evaluated, since having physically available ARSG makes it possible to more realistically test the use case feasibility in practice.

The seventh step is to buy a minimum viable amount of ARSG to implement the case. In this step, the goal is to go from evaluation to implementation. It can be expected that unforeseen challenges will arise at this stage. This step is the most likely to disturb production and precautions should be taken to handle or avoid production down time.

The eight step is to evaluate how well the use case was served by using the ARSG solution. In this step it is also included to evaluate the process. Did the steps provide relevant value or is there a need to modify their content based on the specifics of the use case? Can this be generalized for similar use cases? Step seven in particular will likely present challenges that were not previously identified that can improve the overall process.

6. Conclusion

The application of ARSG has increased over time, including within manufacturing and assembly. As a consequence, there is a growing need for research in identifying key criteria for choosing the right implementation of this technology for different assembly cases. ARSG can be considered as a valuable support for assembly operators, making it essential to consider operator requirements when choosing the most suitable ARSG. Additionally, sustainability is a critical factor to weigh when evaluating any technology, including ARSG. It is also important to understand how the integration of this technology can positively impact sustainability and circularity in manufacturing.

Considering these facts, this paper aims to provide practical guidance on selecting and integrating an appropriate ARSG model for assembly operator support, while improving and integrating sustainability in manufacturing. The theoretical foundation of this paper is based on a narrative review.

As a result, this paper has introduced a comprehensive decision-making process to guide the selection of ARSG for specific use cases. The process considers various aspects, such as use case identification, integration into production, and scale of implementation.

As the ARSG market continues to grow, and the significance of sustainability in manufacturing deepens, the insights and guidance presented in this paper can serve as a valuable resource for organizations seeking to integrate ARSG into their operations while pursuing sustainability objectives. This paper also highlights the need for further collaboration between researchers and the manufacturing industry to test and refine the proposed decision process, ultimately contributing to the sustainable integration of ARSG in the field.

References

[1] Koutromanos G, Kazakou G. Augmented reality smart glasses use and acceptance: A literature review. 2023 [cited 2023 Sep 23]; Available from: https://doi.org/10.1016/j.cexr.2023.100028

[2] Bottani E, Vignali G. Augmented reality technology in the manufacturing industry: A review of the last decade. IISE Trans. 2019 Mar 4;51(3):284–310.

[3] Syberfeldt A, Danielsson O, Gustavsson P. Augmented Reality Smart Glasses in the Smart Factory: Product Evaluation Guidelines and Review of Available Products. IEEE Access. 2017;5:9118–30.

[4] Danielsson O, Holm M, Syberfeldt A. Augmented reality smart glasses in industrial assembly: Current status and future challenges. J Ind Inf Integr. 2020 Dec 1;20.

[5] Augmented Reality Market Analysis & Segment Forecasts To 2030 [Internet]. San Francisco; 2022 [cited 2023 Oct 11]. Available from: https://www.grandviewresearch.com/industry-analysis/augmented-reality-market

[6] Mike Boland. A Spatial Future Materializes [Internet]. 2023 Jan [cited 2023 Oct 10]. Available from: https://artillry.co/wp-content/uploads/2023/07/ARtillery-Intelligence-Sample-Report.2023.pdf

[7] Kim D, Choi Y. Applications of smart glasses in applied sciences: A systematic review. Vol. 11, Applied Sciences (Switzerland). MDPI AG; 2021.

[8] Fang W, Chen L, Zhang T, Chen C, Teng Z, Wang L. Head-mounted display augmented reality in manufacturing: A systematic review. Vol. 83, Robotics and Computer-Integrated Manufacturing. Elsevier Ltd; 2023.

[9] Koren Y, Gu X, Badurdeen F, Jawahir IS. Sustainable Living Factories for Next Generation Manufacturing. In: Procedia Manufacturing. Elsevier B.V.; 2018. p. 26–36.

[10] Stratton SJ. Literature Reviews: Methods and Applications. Prehosp Disaster Med [Internet]. 2019 Aug 1;34(4):347–9. Available from: https://www.cambridge.org/core/journals/prehospital-and-disaster-medicine/article/literature-reviews-methods-and-applications/70581E0B68B491693E8360DE39E0D6E4

[11] Siddaway AP, Wood AM, Hedges L V. How to Do a Systematic Review: A Best Practice Guide for Conducting and Reporting Narrative Reviews, Meta-Analyses, and Meta-Syntheses. Annu Rev Psychol [Internet]. 2019;70:747–70. Available from: https://doi.org/10.1146/annurev-psych-010418-

[12] Baumeister RF. Writing a Literature Review. In: The Portable Mentor. New York, NY: Springer New York; 2013. p. 119–32.

[13] Baethge C, Goldbeck-Wood S, Mertens S. SANRA—a scale for the quality assessment of narrative review articles. Res Integr Peer Rev. 2019 Dec;4(1).

[14] Caudell TP, Mizell DW. Augmented reality: an application of heads-up display technology to manual manufacturing processes. Proceedings of the Twenty-Fifth Hawaii International Conference on System Sciences. 1992;ii.

[15] Azuma R, Baillot Y, Behringer R, Feiner S, Julier S, MacIntyre B. Recent advances in augmented reality. IEEE Comput Graph Appl. 2001;21(6):34–47.

[16] Bimber O, Raskar R. Modern approaches to augmented reality. In: SIGGRAPH 2005. ACM; 2006. p. 1–86.

[17] Peddie J. Augmented Reality: Where We Will All Live. 1st ed. Cham, Switzerland: Springer; 2017. 349 p.

[18] Danielsson O, Holm M, Syberfeldt A. Augmented reality smart glasses for operators in production; Survey of relevant categories for supporting operators. Procedia CIRP. 2020;93:6.

[19] Brundtland GH. Report of the World Commission on environment and development:" our common future.". UN; 1987.

[20] Purvis B, Mao Y, Robinson D. Three pillars of sustainability: in search of conceptual origins. Sustain Sci [Internet]. 2019;14(3):681–95. Available from: https://doi.org/10.1007/s11625-018-0627-5

[21] Hegab H, Shaban I, Jamil M, Khanna N. Toward sustainable future: Strategies, indicators, and challenges for implementing sustainable production systems. Sustainable Materials and Technologies. 2023 Jul 1;36.

[22] Masood T, Egger J. Adopting augmented reality in the age of industrial digitalisation. Comput Ind [Internet]. 2020;115:1–6. Available from: https://www.sciencedirect.com/science/article/pii/S0166361519301186

[23] Danielsson O, Syberfeldt A, Holm M, Thorvald P. Integration of Augmented Reality Smart Glasses as Assembly Support: A Framework Implementation in a Quick Evaluation Tool. International Journal of Manufacturing Research. 2023;

[24] Danielsson O, Holm M, Syberfeldt A. Evaluation Framework for Augmented Reality Smart Glasses as Assembly Operator Support: Case Study of Tool Implementation. IEEE Access. 2021;9:104904–14.

[25] Chen X, Despeisse M, Johansson B. Environmental sustainability of digitalization in manufacturing: A review. Vol. 12, Sustainability (Switzerland). MDPI; 2020. p. 1–33.

[26] Muhammed BJ, Aboobacker R. Environmental Impact Assessment of Augmented Reality Technology Implementation Master's thesis in Sustainable Energy Systems [Internet]. Available from: https://hdl.handle.net/20.500.12380/302944

[27] Cosio LD, Buruk O, Fernández Galeote D, Bosman IDV, Hamari J. Virtual and Augmented Reality for Environmental Sustainability: A Systematic Review. In: Conference on Human Factors in Computing Systems - Proceedings. Association for Computing Machinery; 2023.

[28] Breves P, Greussing E. Virtual and Augmented Reality in Environmental Communication. In: The Handbook of International Trends in Environmental Communication. New York: Routledge; 2021. p. 449–63.

[29] Kerin M, Pham DT. A review of emerging industry 4.0 technologies in remanufacturing. Vol. 237, Journal of Cleaner Production. Elsevier Ltd; 2019.

[30] Comes R, Neamțu C. HEAD-MOUNTED DISPLAY WEARABLE DEVICES ERGONOMICS AND USABILITY. Acta Technica Napocensis-Series: Applied Mathematics, Mechanics, and Engineering. 2023;65(3S).

[31] Kumar NM, Singh NK, Peddiny VK. Wearable Smart Glass: Features, Applications, Current Progress and Challenges. Vol. 10, Second International Conference on Green Computing and Internet of Things. 2018. p. 12.

[32] Sidiropoulos V, Bechtsis D, Vlachos D. An augmented reality symbiosis software tool for sustainable logistics activities. Sustainability (Switzerland). 2021 Oct 1;13(19).

[33] Thiede S, Damgrave R, Lutters E. Mixed reality towards environmentally sustainable manufacturing - Overview, barriers and design recommendations. In: Procedia CIRP. Elsevier B.V.; 2022. p. 308–13.