Using Smart Glasses in Assembly/ disassembly Tasks: State of the Art

By Sylvie Nadeau, Eng., Ph.D.[1], Ralph Bruder, Dr.-Ing.[2], and Lucas A. Hof, Eng., M.Sc., Ph.D.[3]

Résumé

Les lunettes intelligentes font leur entrée dans le secteur manufacturier. Il est donc important de synthétiser les connaissances actuelles sur leur utilité, leur utilisabilité, leurs risques et leur acceptabilité pratique. Une recherche documentaire trilingue portant sur la documentation publiée dans les principales bases de données scientifiques entre 2014 et 2020 a été effectuée. Les lunettes intelligentes ne conviennent pas à toutes les tâches et à tous les contextes de travail. Elles doivent respecter de multiples normes couvrant l'interaction homme-équipement, l'internet des objets et l'équipement de protection individuelle. Des critères de conception, d'utilisabilité et d'acceptabilité pratique ont été proposés. Plusieurs défis demeurent, notamment parce que ces appareils n'ont pas atteint leur pleine maturité technologique. Bien qu'il existe quelques cas réussis de mise en œuvre industrielle, d'autres expériences en laboratoire et sur le terrain doivent être menées pour fournir des lignes directrices claires et détaillées sur l'utilisation des lunettes intelligentes en milieu de travail. Leur développement reste cependant une voie prometteuse pour élargir le bassin de travailleurs disponibles dans le secteur manufacturier. De plus, de tels outils intelligents promettent de contribuer à mieux contrôler les risques de contamination (p. ex., propagation de virus) en réduisant le besoin de contact manuel avec les systèmes d'instructions de montage/démontage (clavier d'ordinateur, souris, écran tactile ou instructions papier) dans les systèmes de fabrication et liés, par exemple, à la COVID-19.

1. S. NADEAU IS WITH ÉCOLE DE TECHNOLOGIE SUPÉRIEURE, MONTREAL, QUE., CANADA, H3C 1K3 [sylvie.nadeau@etsmtl.ca].
2. R. BRUDER IS WITH ÉCOLE DE TECHNOLOGIE SUPÉRIEURE, MONTREAL, QUE., CANADA, H3C 1K3 AND TU DARMSTADT, GERMANY, 64289 [ralph.bruder@itu-darmstadt.de].
3. L. HOF IS WITH ÉCOLE DE TECHNOLOGIE SUPÉRIEURE, MONTREAL, QUE., CANADA, H3C 1K3 [lucas.hof@etsmtl.ca].

Abstract

Smart glasses are entering the manufacturing sector. It is therefore important to summarize current knowledge about their utility, usability, risks, and practical acceptability. A trilingual literature search covering material published in the main engineering databases between 2014 and 2020 was conducted. Smart glasses are not appropriate for all tasks and work contexts. They must obey multiple standards covering human-equipment interaction, the Internet of Things, and personal protective equipment. Design, usability and acceptability criteria have been proposed. Several challenges remain, notably because these devices have not reached full technical maturity. Although a few successful industrial implementation cases exist, more laboratory and field experiments must be conducted to provide clear and detailed guidelines for the use of smart glasses in the workplace. Their development remains, however, a promising avenue towards expanding the pool of available workers in manufacturing. In addition, such smart tools are promising to contribute in mitigating contamination risks (e.g., virus spreading) by reducing the need for hand-contact with assembly/disassembly tasks instruction systems (PC keyboard/mouse/touchscreen or paper instructions) in COVID and Post-COVID manufacturing systems.

Index Terms : manufacturing, practical acceptability, risk, smart glasses, usability, utility

INTRODUCTION

Undoubtedly, manufacturing is in a time of great change and technological advancement by deployment of disruptive technologies such as Industrial Internet of Things (IIoT), Artificial Intelligence (IA), Robotics, Automation and Virtual and Augmented Reality among others (1). This so-called Fourth Industrial Revolution is shaping around these new developments and the manufacturing landscape of tomorrow by a digital integration of an enterprise's physical assets into a digital ecosystem across the full value chain from suppliers to clients. This transition is enabled by deploying smart technologies and real-time data on processes along the entire value (manufacturing) chain. It aims to increase process flexibility, product customization, process efficiency and productivity, and at the same time it aims to reduce time, costs, waste and innovation cycles.

This manufacturing paradigm shift, referred to as "Industry 4.0", demands research and development on both "smart products" and "smart processes". In addition, it will have a significant impact on the workforce (operators, staff, high-qualified-personnel). They need to be trained, adapted and skilled to work in such emerging Industry 4.0 environment; which is among the biggest challenges of the fourth industrial revolution (1)-(3).

Manual labour is still largely deployed for assembly and disassembly tasks, despite the high degree of automation in fabrication processes. This is mainly due to their flexibility, and unique skills such as high sensorimotor and cognitive skills, which cannot be fulfilled by automated systems (4). Support of human activities becomes a central aspect of the design for novel manufacturing approaches including assembly and disassembly tasks opening up new fields of research. Enhanced human – machine interaction is one of the core areas for success of the next generation of manufacturing (2). Wearable technologies can be identified as a major enabler for such enhanced human-equipment interaction and they form an integral part of the IIoT. It has been shown that wearable technology can increase productivity of employees by 8.5 % and life and job satisfaction by 3.5 % (5).

Among the different wearable devices such as smart-gloves, smart-mechanical-tools, smartwatches, and smartphones; smart glasses are among the information assistance wearable devices deployed in a manufacturing environment.

Smart glasses support the real-time exchange of visual data (text messages, videos, pictures), audio content and positional information. They can also run mobile applications and provide directional lighting (6)(11). Smart glasses consist of 1) a head-mounted display in front of one's eyes to present data from an information system operating in the background, 2) a wearable computer for processing and computing power, 3) multiple sensors for information collection as data inputs (2), (12), (13).

Several use cases have been proposed in the manufacturing sector, specifically in assembly. They include the provision of work instructions, assessment of the current state of the process, and the preparation of quality control reports (6), (7), (14)-(17). Smart glasses can also be used in combination with traditional tools and equipment, with other smart devices (18)-(20) or with automated systems (9), (16). Significant integration challenges are to be expected, at both the hardware and software levels (21), (22).

The purpose of this article is to survey the state of current knowledge about the utility, usability, risk and acceptability of smart glasses in an assembly/disassembly tasks context. This comprehensive review study aims to contribute to address the open question of how wearable devices, specifically referring to smart glasses, can be used in a manufacturing context and which limitations are encountered by implementation.

Methods

A search of the French, English and German literature was conducted in the Engineering Village, Scopus and Web of Science databases, using the following keywords: eyewear, smart glass, data glass, ergonomic, human factor, occupational health and safety, and assembly. Coverage of the relevant literature was maximized through the snowball effect. Only work published in the last six years (2014-2020) was retained because of the technology's rapid development. No publications written in French or concerned with disassembly were located. Knowledge was categorized according to the four themes of interest in this review: utility, usability, risks, and practical acceptability, using Nielsen's (1993) framework (23).

Results

3.1 Utility

Smart glasses seem best suited to information sharing during tasks that are either complex (15) (24) or variable (17). They are useful when the workers must be highly mobile (25), when both of their hands are busy (26), or in remote collaborative contexts, whether the work is performed synchronously or asynchronously (27) (28). Beginners seem to benefit from the support provided by smart glasses more than experts do (24).

Considerable amounts of knowledge about human-equipment interaction has been compiled into standards, including for computerized equipment (e.g., ISO 9241-110, ISO 9241-210). Smart glasses must follow these standards (16) (17). Criteria governing the design of wearable devices have been proposed (17) (29). Standards are under development (30) (31). A comparative study of several wearable device usability assessment kits has also been conducted by Terhoeven and Wischniewski (32). What emerges is a consensus regarding the need to match the technical solution with the task at hand, as well as the value of aesthetically pleasant or unobtrusive devices (32). Industry stakeholders, for their part, insist on comfort, ease of use, ease of adjustment, and compatibility with the work to be performed (20).

3.2 Usability

According to Nielsen's (1993) framework, ISO 9241-11 (2018) (33) and ISO/TR 16982 (2002) (34), a usable device is easy to learn and once one stops using it, one can remember how to use it without training, can be efficiently used, error robust (a user makes few errors using the device and can correct an error easily) and subjectively pleasing.

Like any other work tool, smart glasses must provide timely and accurate feedback to the worker (e.g., textual instructions, images, light signals, audio signals, vibrations, status data, positional data), minimize errors, support operational flexibility (e.g., freedom of motion and movement) (7) (8) (15)-(17) (32)-(35)-(36), and be both robust and usable in potentially dusty industrial environments (37) (38). Peripheral vision, crucial to a worker's safety, must not be obstructed (39) (40) (41). Light signals used to warn the operator of an error may go unnoticed under stress, or violate the operator's privacy because they may be visible to peers in certain work situations (42). Haptic feedback has the advantage of protecting confidentiality (42). Providing redundant haptic and visual signals to prevent errors seems like a promising avenue (42).

Smart glasses must answer challenges regarding hand-eye coordination/interference with other objects, the task or other sources of information (9) (15)-(17) (27) (37) (40) (43)-(44). Display issues include information channel saturation (27) and information display ergonomics (e.g., horizontally or vertically, in the upper or lower part of the lenses, highlighting/labels/arrows design, font colors, and background colors, all while maintaining visual comfort and balancing central vs peripheral vision), in a context where the workers must also be able to see their surroundings under variable lighting conditions (16) (17) (25) (39) (45). Issues of weight, weight distribution, and size also need to be addressed for some devices (16) (17) (37) (46), as is the learning curve for new users (16) (20). Consequences for the workers'cognitive workloads are to be expected and mitigated (15) (17).

Glasses being a common consumer good, workers expect an aesthetically pleasing object (16) (17) or a minimalist, unobtrusive one (17). Smart glasses must also be adapted to workers'eyesight conditions (e.g., myopia, presbyopia, astigmatism, color blindness, etc.) and take dominant eyes into consideration (25) (37).

3.3 Risks

Wearing safety glasses is standard operating procedure in factories. Thus, smart glasses used in manufacturing must also fulfill protective functions, with the design, usage and maintenance issues (covered by norms and regulations) that this entails, notably in matters of hygiene (9) (16). Care must also be taken to minimize potential interference with other standard protective equipment (e.g., masks, helmets, gloves and hearing protectors) (9).

3.4 Practical acceptability

System latency and response time influence human performance significantly (17). Like any other smart device, smart glasses must answer challenges regarding battery life (7) (16) (37) and reliability (16).

The relevant literature on smart glasses is mainly focused on ergonomics/human factors considerations, more precisely on their usability aspects.

An important obstacle on a wide adoption of smart glasses for assembly tasks is the dispersion of maturity level (Technology Readiness Level-TRL) of the different elements of smart glasses (47). While the AR displays are developed at high maturity level (TRL 7), other key components such as tracking and user interface are still at lower levels (TRL 5), hindering an adoption of this technology at large scale. Further development and research are needed.

Discussion

While some devices are already available on the market, as are many of the technologies emerging from the 4.0 industrial solution portfolio, the use cases for smart glasses remain to be fully defined, especially in assembly/disassembly tasks. Actual documented case studies are extremely rare, although some from Boeing, BMW, Volkswagen and GE do exist (20) (21). Like many other sectors, assembly and disassembly pose specific challenges; for example: "content is dynamic and interactive, and nearby objects have to be shown for a multitude of near-point tasks" (40). While recent research demonstrates smart glasses'potential as tool to assist in manufacturing operations such as assembly (48), more research is needed.

The literature has shown that stereoscopic 3D technology is also useful in assisting object manipulation (36); in locating, identifying and classifying nearby objects; in estimating object positioning; and in tasks that require understanding and remembering positions in space (23). This makes stereoscopic 3D another promising technology (21) (39) (49), that can be combined with machine or deep learning (50) (51). A synthesis of the current knowledge about this technology is outside the scope of this paper. Smart contact lenses (52), primarily designed to correct certain pathologies of the eye, are under development and may be deployed in other contexts in the future.

Smart glasses usability is somewhat clearer, although many laboratories and field experiments remain to be performed before detailed recommendations can be formulated. While there have been some attempts at standardization, it remains difficult to compare the laboratory protocols found in the literature, largely because of the diversity of tasks and devices under study (23) (26) (28) (53). Trial protocols representative of the reality of "industry 4.0" remain to be designed (35), the simplest assembly/disassembly tasks are susceptible to automation or robotization, not digitalization. There is a wider consensus regarding the data to be measured during these experiments, such as reaction time, task completion time, precision of object positioning in space, and error percentage (23), visual acuity, field of vision, experienced workload, head positioning and movement, and muscular activity in the neck and in the shoulder girdle (11) (54) (55) (56).

One of the major advantages of the Industry 4.0 technological solutions portfolio is that they allow people who have had little or no access to work to receive the support they need to get a job or to remain in the workforce longer (19) (37) (57). Used appropriately and in combination with proper ergonomic/human factors engineering actions, these technologies may support the expansion of the pool of workers available in the manufacturing sector.

In addition, smart tools such as smart glasses are promising to contribute in mitigating contamination risks (e.g., virus spreading) by reducing the need for hand-contact with assembly/disassembly tasks instruction systems (PC keyboard/mouse/touchscreen or paper instructions) in COVID and Post-COVID manufacturing systems (58). This topic may open up new research avenues relating Industry 4.0 technology to post-COVID smart manufacturing systems, leveraging current industries facing challenging times due to adoption of new smart technologies and the current global pandemic situation.

Limitations

It should be noted that the authors are aware of the limitations of the review approach and that this contribution cannot cover all the aspects of smart glasses in assembly/disassembly tasks, due to continuously ongoing and unreported initiatives and the size limitations of the journal. Furthermore, some works could have been excluded by limiting the database search on the chosen keywords. Only peer-reviewed work is considered in this study, while technical magazines and reports were not consulted, which could have revealed additional relevant work in the field of using smart glasses for assembly/disassembly tasks.

Conclusion

The literature on utility, usability, risks and practical acceptability of smart glasses has shown that several use cases remain incompletely defined and that improvements, research and development are still required to take full advantage of this technology. The manufacturing sector needs to expand its worker pool. A few businesses have integrated smart glasses into the workplace successfully. These devices offer promising levels of support for the digital transformation of manufacturing plants.

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