Master Degree Project

UNIVERSITY OF SKÖVDE

USING AUGMENTED REALITY TECHNOLOGY TO IMPROVE HEALTH AND SAFETY FOR WORKERS IN HUMAN ROBOT COLLABORATION ENVIRONMENT: A LITERATURE REVIEW

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Dinesh Chemmanthitta Gopinath

Supervisor: Magnus Holm

Examiner: Sunith Bandaru

Abstract

Human Robot Collaboration (HRC) allows humans to operate more efficiently by reducing their human effort. Robots can do the majority of difficult and repetitive activities with or without human input. There is a risk of accidents and crashes when people and robots operate together closely. In this area, safety is extremely important. There are various techniques to increase worker safety, and one of the ways is to use Augmented Reality (AR). AR implementation in industries is still in its early stages. The goal of this study is to see how employees' safety may be enhanced when AR is used in an HRC setting. A literature review is carried out, as well as a case study in which managers and engineers from Swedish firms are questioned about their experiences with AR-assisted safety. This is a qualitative exploratory study with the goal of gathering extensive insight into the field, since the goal is to explore approaches for AR to improve safety. Inductive qualitative analysis was used to examine the data.

Visualisation, awareness, ergonomics, and communication are the most critical areas where AR may improve safety, according to the studies. When doing a task, augmented reality aids the user in visualizing instructions and information, allowing them to complete the task more quickly and without mistakes. When working near robots, AR enhances awareness and predicts mishaps, as well as worker trust in a collaborative atmosphere. When AR is utilized to engage with collaborative robots, it causes less physical and psychological challenges than when traditional approaches are employed. AR allows operators to communicate with robots without having to touch them, as well as make adjustments. As a result, accidents are avoided and safety is ensured.

There is a gap between theoretical study findings and data gathered from interviews in real time. Even though AR and HRC are not new topics, and many studies are being conducted on them, there are key aspects that influence their adoption in sectors. Due to considerations such as education, experience, suitability, system complexity, time, and technology, HRC and AR are employed less for assuring safety in industries by managers in various firms. In this study, possible future solutions to these challenges are also presented.

Keywords: Human Robot Collaboration, Augmented Reality, Health and Safety

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Skövde, June 2022

Dinesh Chemmanthitta Gopinath

Certificate of authenticity

Submitted by Dinesh Chemmanthitta Gopinath to the University of Skövde as a Master Degree Thesis at the School of Engineering.

I certify that all material in this Master Thesis Project which is not my own work has been properly referenced.

Signature.

Dinesh Chemmanthitta Gopinath

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List of Abbreviations

AR – Augmented Reality

HRC- Human Robot Collaboration

HSE- Health and Safety Environment

SLR- Systematic Literature Review

HRI- Human Robot Interaction

VR- Virtual Reality

CPS- Cyber Physical System

OHS- Occupational Health and Safety

IoT- Internet of Things

PLC- Programmable Logic Controller

HMD- Head Mounted Display

UI- User Interface

GUI- Graphical User Interface

RGB-B – Red Green Blue Depth

SME- Small- Medium Enterprises

1 Introduction

This thesis will look at how AR technology may help workers in a Human Robot Collaborated Environment enhance their health and safety. Literature research is carried out, as well as a case study in which company managers and engineers are interviewed The interview questions will be based on the findings from the literature review. The results from the literature and and interviews will be evaluated qualitatively to see whether there are any concepts or conclusions that are similar in both circumstances. The problem is described in the first chapter, along with the research question, objectives, and the whole research method.

1.1 Problem description

Production organization activities require a level of safety. These organization will have safety regulations and procedures that all employees must follow. It not only contributes to the preservation of a safe environment, but also to the enhancement of one's quality of life. Occupational Workplace health and safety aid in the reduction of workplace accidents and challenges. When technology evolves on a daily basis, there is a high priority placed on safety. Industry 4.0, for example, enables businesses to reduce human interaction. Unlike pre-revolutionary production techniques, which separated human operators and robotic complexes based on safety rules, advanced robotics and a collaborative human interaction system/human robot collaboration are used in production, allowing the operator and robot to work in the same space. In contrast to typical robots that work in fences, operators collaborate with robots. As a result, a number of communication technologies, such as virtual reality and augmented reality may be used to increase the safety of different situations. AR is a type of virtual reality that superimposes a virtual environment on top of the actual world. We may use AR features like spatial planning, sound, and visual critique to re-enact a variety of real-world situations. It's vital to remember that when companies operate with less human effort, health and safety are critical considerations. Using AR, some potentially dangerous acts in the HRC environment may be analyzed and investigated. Learning about the advantages and disadvantages can aid in the planning and creation of a safe environment for human-robot collaboration.

1.2 Aim and objectives

This study aims to find the how augmented reality technology can improve the safety for workers in a HRC environment. The research question is*: How Augmented Reality can improve the Health and Safety for workers in a Human Robot Collaboration Environment*? The objectives of this thesis include:

1. *Literature study about Augmented Reality, Human Robot Collaboration Environment and Health and safety in industries*
2. *Analyze existing literature to study how AR can improve worker safety and working environment by existing technologies and their challenges*
3. *Interviews with managers and engineers based on findings from literature.*

The research is qualitative in nature. A comprehensive literature review is conducted, as well as a case study in which firm managers and engineers are interviewed. The findings from the literature research will be used to create interview questions. This will aid the thesis in gathering additional real-time data and validating it with theoretical article publications. A cross validation of data is being planned in order to have a more in-depth understanding of the current circumstance. The oveall research design is shown in Figure 1.

Research Strategy	Data Collection Methods	Data Analysis Method
Case study	Literature review & interviews	Qualitative analysis

Figure 1 Research Design

The Methods to achieve the objectives are as following:

1. Conduct a Systematic Literature Review (SLR)
2. Conduct semi- systematic interviews with mangers and engineers
3. Analyze the findings through inductive qualitative analysis to find themes and patterns
4. Triangulate the findings from SLR and Interviews

The overall research plan for the study is described in Figure 2.

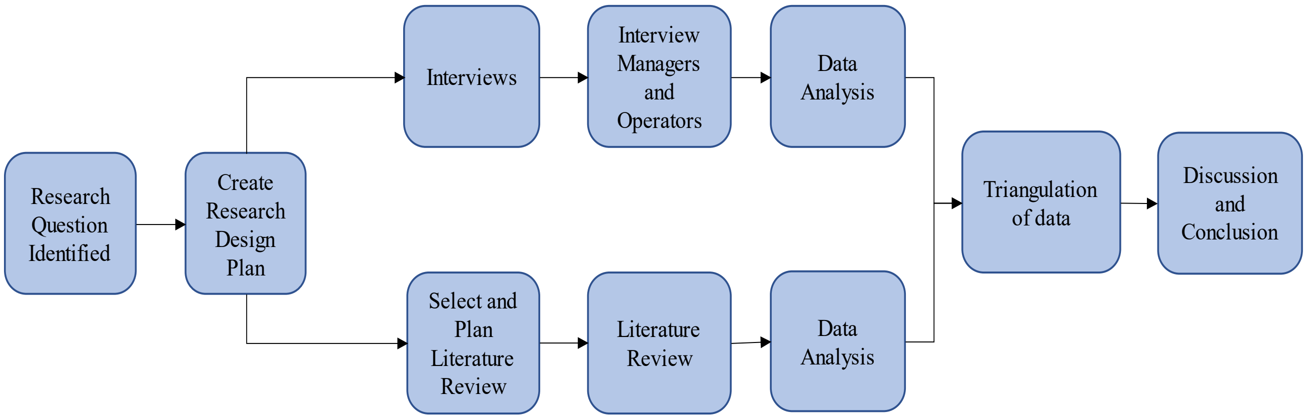

Figure 2 Research Plan

1.3 Limitations and scope

Augmented reality is utilized in a variety of applications, including manufacturing and assembly guidance, product design, assembly design, product maintenance, and robot trajectory planning and simulation (Michalos, et al., 2015). They're also employed in a variety of industrial settings, including medical, aerospace, and power plants. For the time being, only automation and manufacturing enterprises who use HRC are interviewed. This study excludes the participation of other industries. In firms that do not employ AR technology, research interviews are also conducted. This research discusses their experience and understanding of robot safety, as well as their thoughts for employing AR in their HRC setting. Even if AR is not a new concept it is not widely used among industries due to different challenges. Therefore organizations that adopt AR is very less. Some of the challenges of AR and HRC in industries are explained in this research.

The following is a breakdown of the report's structure: Theoretical concepts in the research is introduced in Chapter 2. The research strategy and methods are given in Chapter 3. The literature research technique, findings, and analysis are all reported in Chapter 4 of the literature review. In chapter 5 the implementation, results, and analysis of the case study are described. The results from the case study are summarized in chapter 6. In chapter 7 conclusions are drawn based on the results, recommendations are presented and future work is suggested.

2 Theoretical framework

In this chapter, a study based on research characteristic is given, which includes Human Robot Collaboration Environment, Augmented Reality and Health and Safety.

2.1 Human robot collaboration environment

The Human Robot Collaboration Environment is a place where humans and robots interact with each other. Human robot collaboration is evolving on a daily basis with the introduction of new technologies. The Automation stage of the third industrial revolution uses PLCs to assist people operate robots with minimal human interaction. Industry 4.0, or the fourth industrial revolution, is taking its place, with the help of the internet and communication technology. Cyber Physical Systems (CPS), the Internet of Things (IoT), Smart Factories, and other advanced technologies assist corporations in reducing human labor. This allows robots to handle a situation without the assistance of humans.

Collaboration between people and robots is viewed as a realistic technique for boosting productivity and cutting manufacturing costs by combining the robot's fast repetition and high output capabilities with a human operator's capacity to analyze, adapt, and plan (Tashtoush et al., 2021). This will expand the number of robots in the world and their application in various sectors. Every industry is increasingly focused on automation to relieve work load and stress for their employees. According to (Siegfried and Ismaeel, 2022) robotic systems will be used to automate activities in the fields of logistics, health, and utilities in the future.

When compared to traditional robots, collaborative robots have several advantages. Unlike traditional robots, which are kept in cages and segregated from employees in the workplace, advances in Industry 4.0 allow businesses to combine humans and robots to complete jobs. Figure 3 depicts a comparison between collaborative and traditional robots. Traditional robots take up more room and require barriers to keep them separate from humans, whereas collaborative robots (Cobots) do not. The use of sensors and cameras allows the robot to determine the human's location and avoid collisions.

Figure 3 Collaborative robots and traditional robots (Vysocky and Novak, 2016)

"Human Robot Interaction (HRI) systems are characterized as "workspace sharing" or "workspace and time sharing" depending on their purpose." (Michalos et al, 2015). Both human operators and robots, according to the authors, are capable of executing solo or cooperative tasks. The operator must be a supervisor, operator, teammate, mechanic/programmer, and bystander. HRI systems can be further categorized based on the level of engagement. The robot and the human operator may be allocated a common task and workspace, a shared task and workspace, or a common task and a separate workspace. Figure 4 depicts this. In the second circumstance, the human operator and the robot share tasks and workspace, but their connection is distinct.

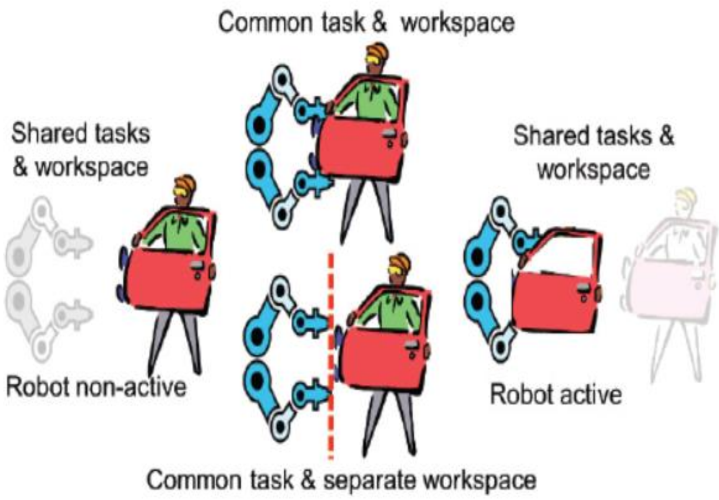

Figure 4 Human robot collaborative tasks and work space (Michalos et al., 2015)

A collaborative robot may be tailored to a number of different applications and scenarios. It is possible to adjust the grips and claws to complete the task depending on the assignment. As a result, they are employed in a wide range of applications, from medicine to the safe operation of nuclear power plants.

2.1 Augmented reality

Augmented reality technology has been around since the 1950s, when Morton Heilig, a cinematographer, thought of film as an activity that could bring the viewer into the onscreen action by effectively incorporating all of the senses (Carmigniani and Furht, 2011). AR technologies can be classified in to two categories AR devices and AR Interaction. The most prevalent components of AR devices are displays, input devices, trackers, and computers. AR interactions include tangible AR interfaces, collaborative AR interfaces, hybrid AR interfaces, and the emerging multimodal interfaces. According to (Carmigniani and Furht, 2011) By utilizing the usage of actual, physical tools and things, tangible interfaces promote direct engagement with the physical world. Multiple screens are used in collaborative interfaces to accommodate both co-located and distant operations. Co-located sharing enhances the actual collaborative workspace through the usage of 3D interfaces. Hybrid interfaces combine a variety of various yet complimentary interfaces with the ability to communicate via a variety of communication tools. They offer a versatile platform for spontaneous, daily contact when the sort of interaction display or devices to be utilized are not known in advance. Multimodal interfaces integrate input from actual objects with language and behaviors that occur naturally, such as voice, touch, natural hand movements, or gaze. These interfaces are more lately starting to appear (Carmigniani and Furht, 2011).

There are several kinds of AR. Augmented reality technology may be categorized as Markerless AR, Marker-based AR, Projection-based AR, and Super imposition based AR, according to (Yassir & Salah-ddine, 2018). In marker-based AR, the AR device uses camera scan and image recognition to determine the position and orientation of a marker to place the information. As a result, a marker starts digital animations that viewers may observe, transforming magazine photos into 3D models. In markerless augmented reality, data is shown based on the user's location and is provided via a GPS, a compass, a gyroscope, and an accelerometer. The AR material you discover or get in a certain location is therefore determined by this data. In projection-based augmented reality, artificial light is projected onto real-world surfaces, sometimes enabling interaction. In superimposition-based AR, the original vision is completely or partially replaced by an augmented one. The notion simply cannot exist without object recognition, which is essential to the process (Yassir & Salah-ddine, 2018). Figure 5 shows the images of different types of AR explained.

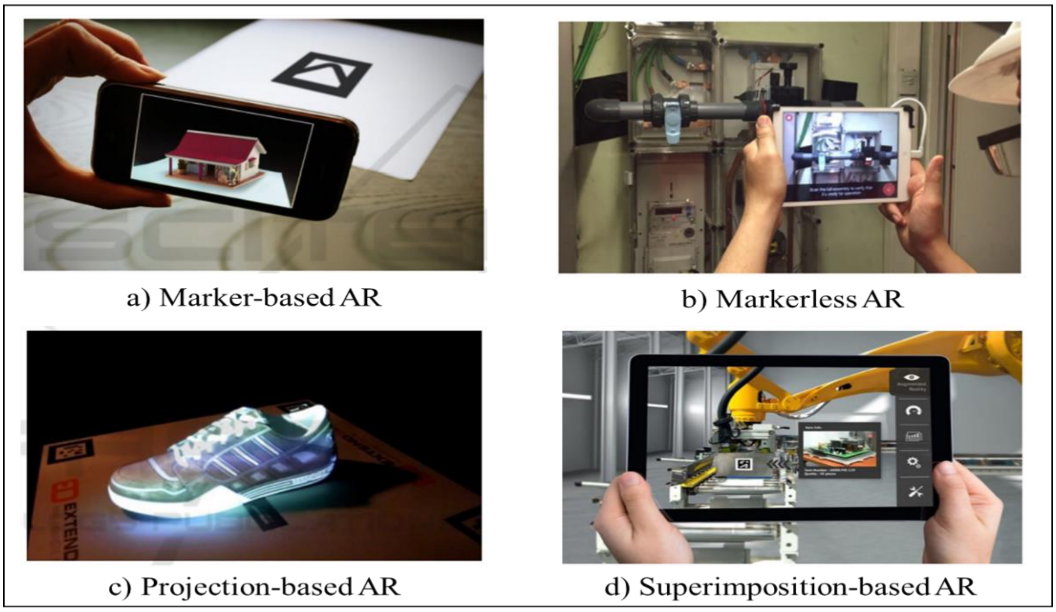

Figure 5 Different types of augmented reality (Yassir & Salah-ddine, 2018)

Another type of AR technology is augmented reality with a head-mounted display (HMD) (Carmigniani and Furht, 2011). HMD is a display device worn on the head or as part of a helmet and that places both images of the real and virtual environment over the user's view of the world. Figure 33 shows an example of HMD- AR.

Figure 6 AR Head mounted display (Carmigniani and Furht, 2011)

In contrast to virtual reality, augmented reality enhances rather than replaces reality. The entire real world is replaced by computer images in a virtual environment. Humans may interact with virtual items in real time thanks to augmented reality. In VR, the user is transported into a virtual universe, but in AR, the user may interact with real-world things. AR is a step ahead of VR since it can combine both real and virtual components at the same time in real space.

According to (Green et al., 2008) AR is an ideal solution for Human Robot Collaboration due to certain factors; The power to make reality better is the greatest advantage of AR. Which also helps in seamless transition between the actual and virtual worlds. It provides the ability to share remote views (ego-centric view) along with the visualization of the robot in relation to the job space (exo-centric view). AR support for transitional interfaces that allow users to seamlessly shift from reality to virtuality.

People and machines may cooperate more easily with the usage of AR technology in Industry 4.0. AR is useful not just for enhancing operator throughput, but also for providing assistance to workers who are cognitively challenged (Bonavolont´a et al., 2020). AR is employed in a variety of collaborative and commercial applications. It's utilized in marketing, education, entertainment, medical applications, and even mobile phone apps. AR applications have benefited workers in areas like as device and system maintenance and repair, manufacturing and assembly, collaboration, management, and product design and training techniques (Tatić, 2018). AR technology not only assists workers in performing tasks, but it also improves their workplace safety. Operators may operate on a virtual representation of a robot in real space and adjust its settings and configuration without having to enter the area. It enables personnel to do maintenance on robots that are difficult to reach or dangerous, such as those at nuclear power plants (Eursch, 2007). It allows businesses to show their clients the design of a factory or plant in a virtual model rather than having to build one. This allows companies to adjust the design based on the preferences of their customers. As a result, clients save time and get a good sense of how the actual plant/factory would look. AR might be described as the design of the future.

2.2 Health and safety

Management of Occupational Health and Safety is a part of a company's overall management system. The Occupation Health and Safety management system includes organizational structure, planning, responsibility, execution, procedures, processes, and resources (Wahana and Hasanati Marfuah, 2020). In an organization, the major goal of health and safety is to establish a safe atmosphere and decrease workplace accidents. The Occupation Health and safety authorities collaborate with supervisors, managers, and operators to establish a more efficient and accident-free workplace and work method.

There are several techniques for guaranteeing the safety of human operators in a Human Robot Collaboration environment, according to (Michalos et al., 2015). According to the author, some of these can be avoided by implementing a crash safety system, which allows only "safe"/controlled collisions between robots, people, and obstacles. Proximity sensors, vision systems, and force/contact sensors are used to detect potential collisions between humans and equipment and to safely stop the activity. Finally, adaptive safety intervenes in the hardware equipment's operation and takes corrective action to avoid crashes without stopping the unit.

Several ISO standards were put in place and are periodically updated in an attempt to identify HRC in a general and robot safety context, according to (Chrysostomou and Hjorth, 2022). The HRC vocabulary, the context of robotics, the interaction between humans and robots (HRI), and other pertinent words linked to robots and control systems/strategies are all defined under the ISO 8373 (ISO, 2016a)standard. In general, the ideas of collaboratively enabled robots, workspaces, and operations are described in the ISO 10218-1/2 (ISO, 2012a: ISO, 2012b) standard. By adding to the criteria and recommendations outlined in ISO 10218, ISO 15066 (ISO, 2016b) makes an effort to further define HRC. More specifically, this standard specifies the right way to restrict speed values so that force and pressure values remain below the specified pain threshold for people in robot collision scenarios (Chrysostomou and Hjorth, 2022) . The purpose of introducing these standards is to identify the various types of cooperation and interaction based on their kind (e.g., verbal, non-verbal), severity, and control modalities. Because technologies allow humans and robots to work close together without boundaries, safety is a critical consideration in the Human Robot Collaboration Environment. In a Human Robot Interaction workstation, proper training, certification, and safety precautions are critical considerations.

3 Methodology

The research strategy is described in this chapter. The study is divided into two parts, the first of which is the data gathering portion and the second of which is the data analysis part. This chapter discusses the research's primary strategies and distinct data gathering methodologies.

3.1 Research design

The study employs a qualitative approach rather than a quantitative method. Since qualitative research is a means for studying and comprehending the importance of a social or human situation as expressed by individuals or a group of individuals, it is a way for examining and comprehending the significance of a social or human situation (Creswell, 2014). Qualitative research is differentiated by the fact that it is performed in a natural setting in which the viewpoints of the participants are valued, and it typically takes a holistic approach to building a thorough picture of the problem (Creswell, 2014). The use of AR to improve worker safety is investigated in this study. As a result, this study takes a qualitative exploratory approach. The research is plan is divided in to two parts where first part deals with the problem formulation and data collection. Second part of the thesis delas with the analyzing of the data and discussions. The research approach utilized in this study is a case study since the research focuses on a single case. A case study might employ a variety of data collecting techniques. The data gathering procedures for this study are anticipated to be a literature review and interviews. Five data sources are used to conduct a systematic literature review. Guidelines for the interviews are created using the findings from the literature review. Second-generation data collecting method include interviews. This will aid in the validation of the data with real-time results. Figure 6 shows the overall structure of the research division plan. It is divided in to two parts, first part up to data collection and second part upto data analysis.

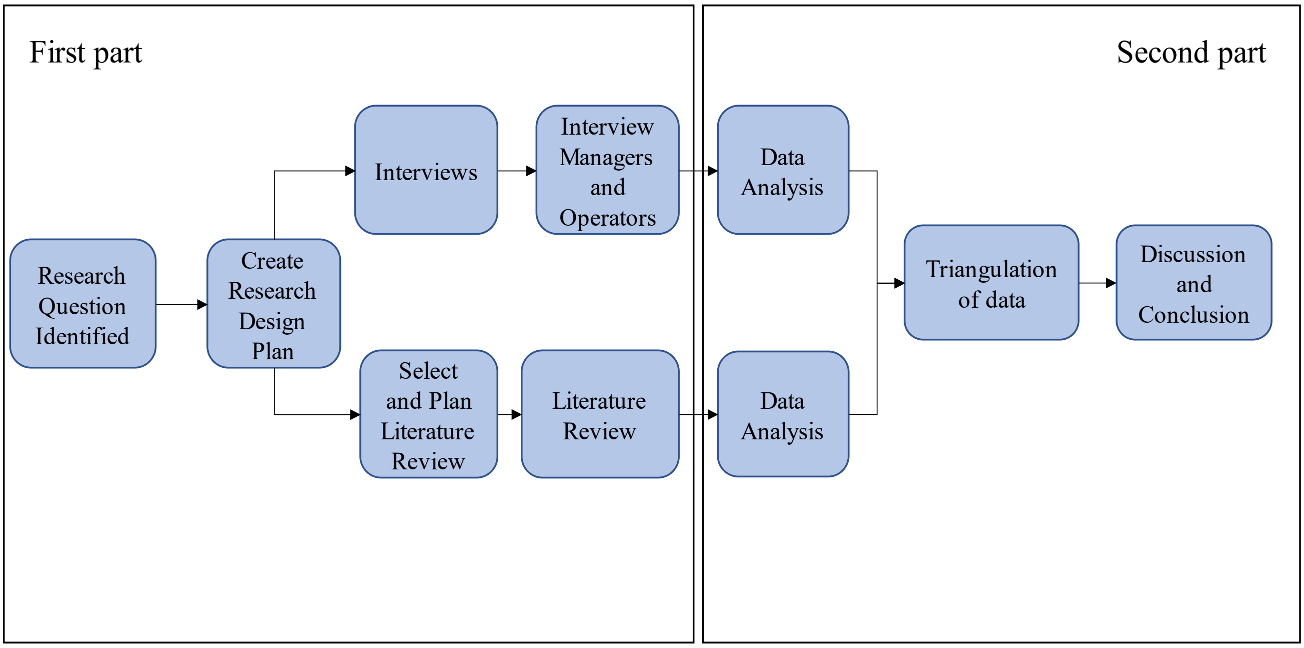

Figure 7 Research division plan

3.2 Research strategy: case study

Different sorts of research strategies exist. The problem that has to be solved will dictate the strategy to use. There are several research methods available, including ethnography, experiments, surveys, and case studies (Oates, 2006). Because this study is focused on a single case, the research technique is case study. A case study might employ a number of data collecting techniques. In this study, two data gathering methods such as interviews and literature reviews are used to gain additional knowledge and in-depth understanding of the case. This is why the case study method was chosen for this thesis. There are three different sorts of case studies (Oates, 2006). Case study that is exploratory, explanatory, and descriptive. An exploratory case study is used in this strategy.

3.3 Philosophical paradigm: constructivism

This study used a constructive paradigm, which is common in qualitative research. According to constructivism, people are looking for meaning and understanding in their lives and work. Researchers must embrace the participants' opinions and look for complexity since the meaning of people's experiences is subjective and multidimensional (Creswell, 2014).

3.4 Data collection methods

Systematic Literature review and interviews are the data collection methods used in this research.

3.4.1 Systematic literature review

Literature reviews are useful for presenting an overview of a certain subject or research problem. (Snyder, 2019). A literature review is useful for learning in depth about a study topic and keeping our knowledge current. Reading prior work will also aid in determining the current worth of the research. The goal is to find all empirical data that meets certain criteria in order to answer a specific research question or hypothesis (Snyder, 2019).

According to (Snyder, 2019) literature review is classified into three. Integrated, semi-systematic, and systematic The data for this study was gathered by a Systematic Literature Review (SLR). The goal of SLR is to learn about the work that has been done in this field of study as well as the existing technology and their problems. When evaluating papers and other relevant material, bias may be eliminated by using clear and methodical methods that result in reliable findings from which inferences and judgements can be drawn (Snyder, 2019). According to (Oates, 2006), the literature review is separated into seven steps: seeking, acquiring, assessing, reading, critically evaluating, and producing a critical review. Chapter 4 explains how to conduct a literature search. Prior to the search technique, a method for getting distinct search phrases is described, in which the full study topic is presented in a phrase, then the words are split down into separate concepts, with a list of possible keywords for each concept. The concepts are then blended in various combinations throughout the database search. The outcomes of the analysis are then categorized and mapped into distinct contexts. In the results section, these ideas are further developed.

3.4.2 Interview

According to (Oates, 2006) there are three types of interview patterns. Interviews can be organized, semi-structured, or unstructured. Because this is an exploratory study, it is necessary to conduct follow-up questions in order to obtain further information about the case. In the first half of the interview, structured questions are asked, followed by unstructured open inquiries. According to the interview protocol followed in this study (Patton, 1990). Although the interview guide provides a framework with a set of pre-determined themes and questions, the answers influence the flow of the subjects and

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can lead to further questions. The concerns or questions can be stated in an interview guide, ensuring that each individual follows the same fundamental line (Patton, 1990).

According to (Gibbs, 2018) it is not required to transcribe the information if the focus is on the larger picture, even though notes will be taken and the material may need to be reviewed several times. As a result, the content of the interviews will not be entirely transcribed, as the goal is to concentrate on the overall picture. However, the information will be indexed so that it can be easily found again, and some of it will be transcribed. Inductive analysis of the interview allows the evidence to speak for itself rather than deductive interpretation. Following that, each unit in the text will be categorised according to Oates (2006), with headlines, underlines, or other levels that clarify the subject. The categories will then be developed, with themes and connections found between them. The interview findings are examined by looking for common themes and patterns in the literature research and other interviews. After then, the data is triangulated for discussion.

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4 Literature review

The literature review is covered in this chapter. The search procedure is detailed, followed by the findings and analysis.

4.1 Literature search steps

The data for this study is gathered by a systematic Literature Review (SLR). As shown in Figure 7, the technique for carrying out this operation is separated into three steps. Concepts and phrases are defined based on a research phrase, followed by an article search in databases and analysis of the findings.

Literature search steps
1. Identify concepts and themes 2. Database search 3. Analysis results

Figure 8 Literature search procedure

4.1.1 Step1: Identifying concepts and themes

In this stage, the study title's primary concepts are sorted into four groups according to (Oates, 2006) explained in section 3.4.1 (Table 1), and terms with comparable meanings are collected from articles and other sources (Table 2). The research is broken into three parts with the title *Using augmented reality technology to improve the health and safety for workers in human-robot collaboration environment.* Augmented reality, health and safety and human- robot collaboration environment.

Table 1 Division of Concepts

Concept 1	**Concept 2**	**Concept 3**
Augmented reality	Health and safety	Human-robot collaboration environment

Synonyms and similar-sounding terms are sought. Reading a variety of articles also supplied new words to use in these expressions. (See Table 2). These concepts are searched in the database to collect papers relavant to the research which is explained in next step.

Table 2 Alternate words for concepts

Concept 1	Concept 2	Concept 3
HMD-AR	Safeness	HRI
Projective AR	Freedom	Smart Factories
	Defence	Collaborative Robot
Marker based AR	Security	Cobots
Markerless AR	Shelter	ROBO-PARTNER

4.1.2 Step 2: Database search

For this investigation, five scholarly databases were considered. They include Academic Premier, Scopus, Google Scholar, IEEE, and Web of Science. Because these databases contain a huge number of engineering publications that are relevant to the research. The selected papers references are further evaluated in order to find some relevant papers. The literature was found by searching databases for titles, abstracts, and keywords. The AND and OR Boolean operators were used to do the search. Searching is also done with the alternative terms that have been collected. For example, *"Augmented Reality AND Human Robot Collaboration Environment," "Augmented Reality AND Health and Safety," "HSE in Human Robot Collaborated Workspace," "Augmented Reality AND Health and Safety OR Human Robot Collaboration,"* and *"Augmented Reality AND Health and Safety OR Human Robot Collaboration." "Human Robot Interaction, OR Augmented Reality AND Health and Safety"* and so on. Figure 6 depicts an overview of the conducted literature review.

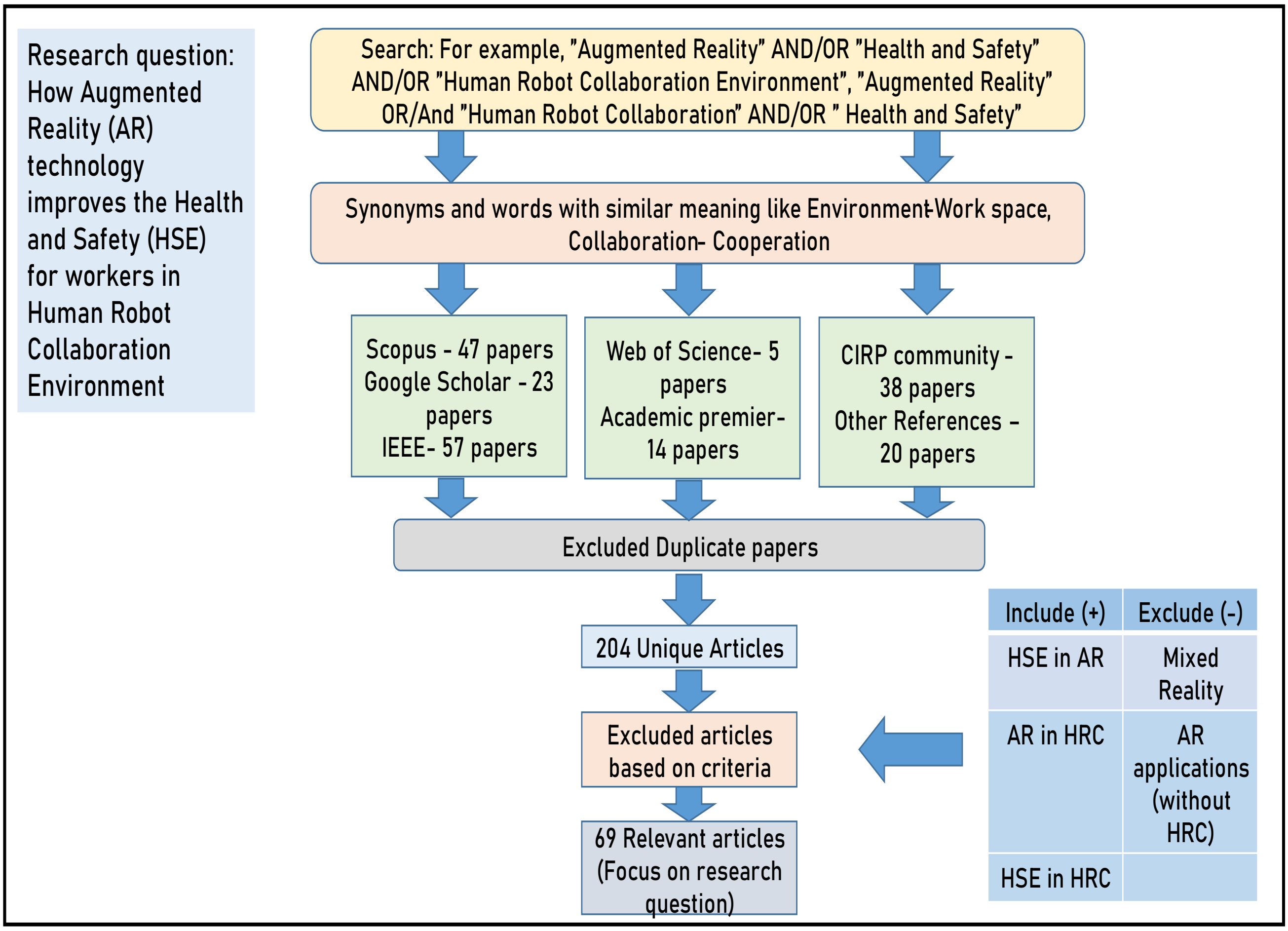

Figure 9 Systematic literature review

The articles are reviewed, sorted, and filtered using the criteria shown in Figure 8. The publications that do not focus on the subject are categorized and archived for future studies. Scopus, Google Scholar. IEEE are the databases which are first used for searching the papers. From these databases 127 papers are collected Figure 8. All these papers are saved in the system as per titles which helped to find whwn duplicate files are received. These collected papers are then thoroughly read after similar searching done in web of science, Academic premier and other references. These three sources yielded a total of 39 papers. There are two dupilicate articles being deleted resulted in a total of 166 articles. These 164 papers are extensively studied with a focus on the research's goal. While reading CIRP annals, several authors' works piqued my curiosity, therefore more search into CIRP annals and individual writers is performed. There are a total of 38 papers in this collection. Filtering these articles based on the criteria and outcomes of 16 related articles. A total of 204 publications were gathered, with 69 relevant articles being chosen for the literature evaluation.

There are certain limitations to this study, such as only using studies that focus on improving safety with AR in HRC environment is used in this research. The rest of the articles that focus on mixed reality, AR without HRC and HSE without AR and HRC are eliminated. Every item was meticulously scrutinized, and any interesting ideas or findings were documented in a search method. Figure 9 depicts a timeline of the publications utilized in the literature review.

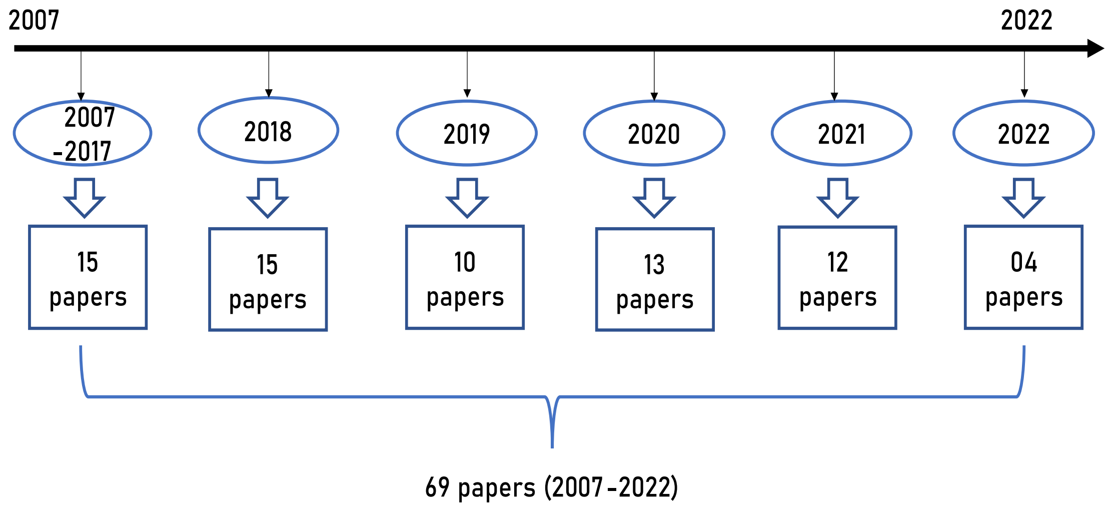

Figure 10 Time chart

The papers are then extensively read in light of the project's goals. The papers were examined three times in order to obtain satisfactory findings. Table 3 shows the list of papers that were utilized to perform the literature review. The numbers in the list are for the literature review only, and should not be confused with the reference list in the main report.

Table 3 Literature review articles

Sl. No	Literature review articles	Sl. No.	Literature review articles
1	Sebastain Blankemeyer., et al. 2018	36	Georgios Tsamis, et al 2021
2	Christine T. et al, 2020	37	Francesco Bonavolont´a, et al. 2020
3	Francesco De Pace, et al. 2020	38	Daniel Szafir, 2019
4	Soheila Sheikh Bahaei 2020	39	Siyuan Xiang, et al 2021
5	Mario Gianni, et al. 2013	40	Ricardo Eiris, et al. 2018
6	Sonia Mary Chacko, et al. 2019	41	Christian Vogel, et al 2020
7	Christos Gkournelos, et al. 2018	42	Jared A. Frank, et al. 2016
8	Antti Hietanen 2020	43	Morteza Dianatfar, et al. 2020
9	Oscar Danielsson. et al, 2017	44	Dominykas Strazdas, et al. 2021
10	George Michalos, et al. 2016	45	George Michalos, et al 2014
11	Konstantinos Lotsaris, et al.2021	46	Jana Jost, et al. 2018
12	Zhanat Makhataeva, et al. 2020	47	Valeria Villani, et al. 2018
13	Francesco De Pace, et al 2019	48	Zhanat Makhataeva, et al 2019
14	Sotiris Makris, et al. 2016	49	George Michalos, et al 2018
15	Andreas Riegler, et al.2021	50	Dinh Quang Huy, et al. 2017
16	Ramsundar Kalpagam Ganesan, et al. 2018	51	Giancarlo Avalle, et al 2019
17	Dario Luipers and Anja Richert 2021	52	Gabriele Bolano, et al. 2020
18	Gabriele Bolano, et al. 2021	53	Dennis Sprute, et al. 2018
19	George Michalos. et al. 2015	54	Gabriel de Moura Costa, et al. 2022
20	Riccardo Palmarini, et al.2018	55	Eleonora Bottani & G. Vignali 2018
21	Yao Huang, 2021	56	Scott A. Green, et al. 2008
22	Zhihao Liu, et al.2020	57	Edoardo Lamon, et al.2019
23	Johannes Egger & Tariq Masood, 2019	58	Zhenrui Ji, et al. 2021
24	Jan Guhl, et al. 2018	59	Angelos Argyrou. et al. 2018
25	Scott A. Green, et al. 2008	60	Ryo Suzuki, et al.2022
26	Christian Vogel, et al. 2012	61	Ana Correia Sim˜oes, et al 2022
27	Yuanzhi Cao.et al. 2019	62	Wei Fang, et al. 2021
28	Patrik Gustavsson, et al.2018	63	Kasper Hald, et al. 2020
29	Scott A. Green, et al. 2008	64	Zdenˇek Materna, et al. 2018
30	Sebastian Hjorth & Dimitrios Chrysostomou, 2022	65	Dionisis Andronas, et al.2021
31	Eloise Matheson, et al 2019	66	Christian Vogel, et al. 2017
32	Shuwen Qiu, et al. 2020	67	Nikos Dimitropoulos, et al. 2021
33	Ondrej Kyjanek, et al. 2019	68	Dawi Karomati Baroroh, et al. 2020
34	Andreas Eursch, 2007	69	Filippo Brizzi, et al 2017
35	Mario Lorenz, et al. 2018		

4.1.3 Step 3: Analyse the results

Machi and McEvoy (2016) suggest organizing the core maps and outlines related to the themes, creating a historical log out of scanning processes, arranging maps, core ideas, keywords, and notes to build up evidence categories, and applying a warrant scheme to each theme group in a three-step process. To begin, categories were discovered in the data. The items were then organized into categories. Third, the categories were fine-tuned once again. The three steps used for data analysis in this research are

1. Find categories
2. Map articles into categories
3. Refine categories

Step 1: To begin, all of the articles found through the 4.1 search technique were organized into a matrix containing the key categories that are relevant to subject and research question. 44 categories are find out.

Step 2: The 69 articles were then mapped into the given categories. The papers that talks about different categories are also mapped accordingly (Appendix A). These categories are then refined again and similar categories are grouped together to form main categories. Only seven categories left. *Visualization, Ergonomics, Awareness, Collision Avoidance, Communication, Training, and Trust* are all important concepts to consider (Appendix B). Categories that were not relevant to the study issue were eliminated (Appendix C).

Step 3: In the last stage, the categories and subcategories were processed to a higher abstraction level in a creative process that included idea color coding. The categories were restructured, rearranged, and renamed until they all fit together well (Appendix D).

Four main categories emerged. The biggest one was visualization, which is mentioned in 43 articles. The second-biggest category, awareness, is mentioned in 37 articles, the third category, ergonomics, is found in 32 articles, and fourth communication 16 articles. See Figure 13, where the subjects are listed as well as the mapped articles, out from the internal numbers showed in Figures 10 and 11.

Categories	Articles	Number
Visualization (Instructions, Information, Training, guidance)	3, 10, 11, 12, 13, 14, 16, 17, 18, 19, 20, 22, 23, 24, 25, 29, 26, 27, 28, 30, 31, 33, 34, 36, 37, 38, 39, 40, 41, 42,43, 44, 46, 47, 48, 52, 54, 53, 59, 60, 62, 66, 69	43
Awareness (Situational awareness, Spatial awareness, Collision avoidance, Trust)	2, 5, 10,12, 13, 14, 16, 18, 20, 22, 23, 24, 25, 26, 29, 30, 32, 34, 36, 41, 42, 43, 44, 46, 48, 50, 51, 52, 54, 56, 57, 58, 60, 62,63, 65, 66	37
Ergonomics (Physical, Cognitive)	3,5,6, 8,10, 12,14,16,17,18,20,23,34,36,41, 42, 45, 46, 47, 48, 49,50,51,52, 54, 55,57,61,64,65,67,68	32
Communication (Verbal, Non-verbal)	2, 7, 11,13, 16, 25, 28, 29, 30, 42, 43, 44, 45, 47, 56, 57	16

Figure 11 Top 4 literature review categories

The rank of categories according to descending order is shown in Figure 14. Picture A shows the results of categories emergerd initially and picture b represents the final list of categories after refining them.

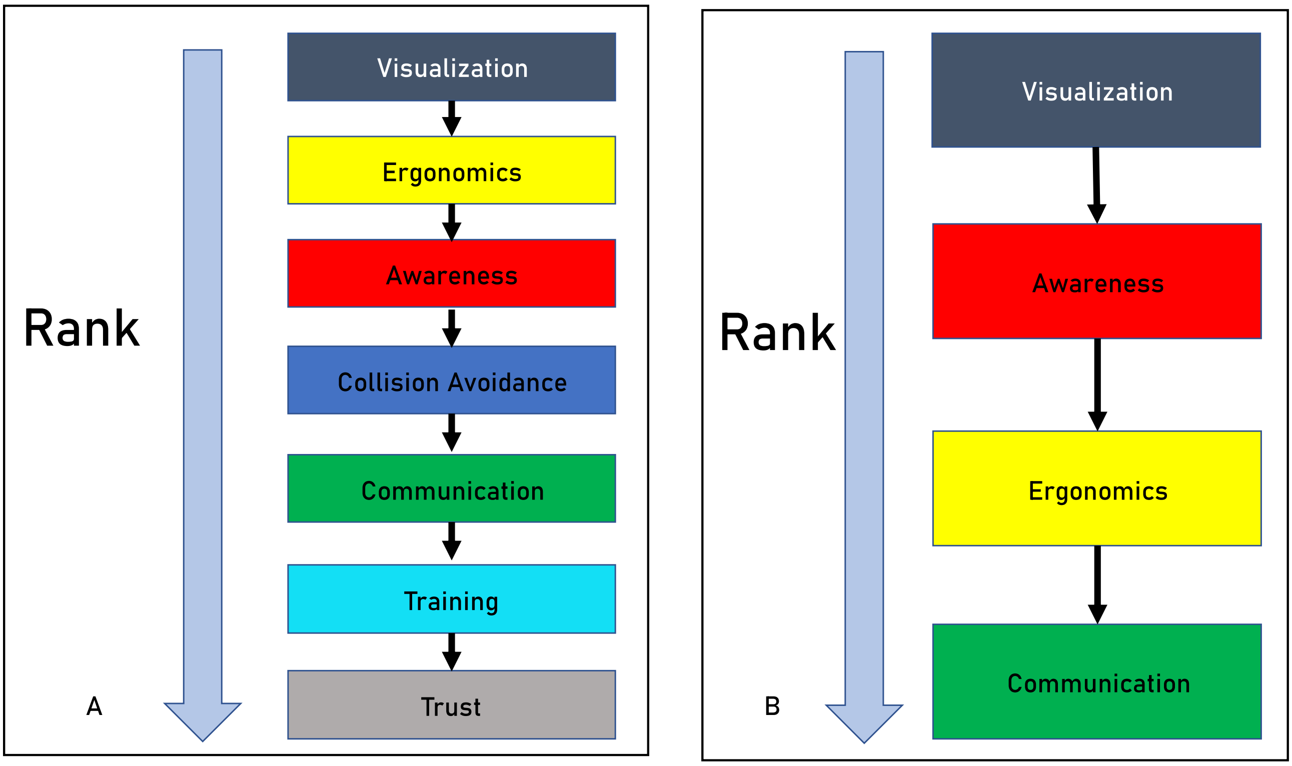

Figure 12 Rank of categories

Subcategories were assigned to each category based on the subjects, as illustrated in Figure 15. Visualizing instructions, information, risk, and concepts like training are all included in the visualization area. The awareness category includes spatial and situational awareness, as well as collision avoidance and human variables like trust. Ergonomics, the third category, includes both physical and cognitive ergonomics. Communication is the fourth category, which includes both verbal and nonverbal communication.

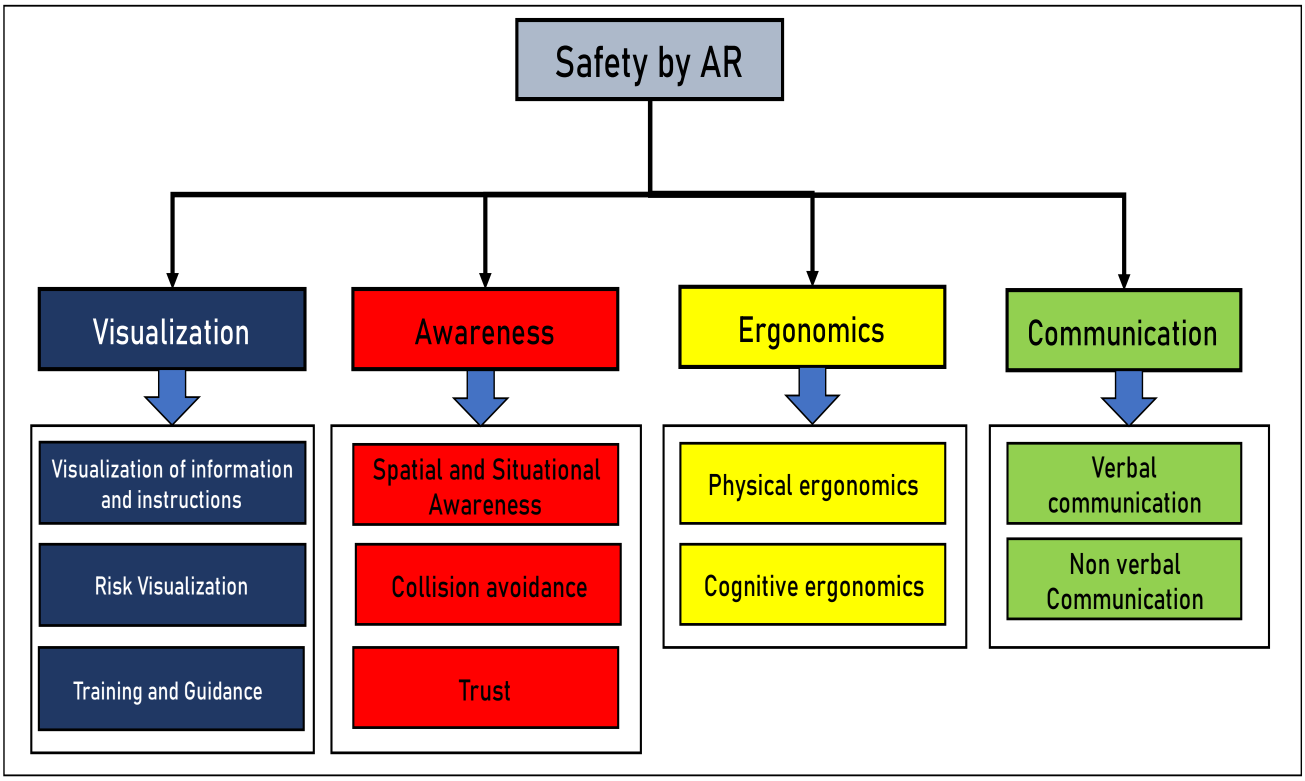

Figure 13 Categories and sub categories of concepts from literature review

4.2 Discussion on identified concepts

In this part, the result will be presented, out from the main categories found in the analysis, namely visualization, awareness, ergonomics and communication along with the sub categories to each category.

4.2.1 Visualization

This section covers topics related to how visualizing promotes safety. Instructions, information, risk, training, and guiding are all aspects of visualization.

Visualizing instructions and informations*:* One of AR's primary features is the ability to visualize both actual and virtual content. Using AR to visualize instructions improves safety by reducing errors and mistakes. The processes for completing the assembly can be simply comprehended with the help of AR and enhances task efficiency as a result (Argyrou, et al., 2018; Danielsson, et al., 2017; Ganesan, et al., 2018; Lotsaris, et al., 2021; Michalos, et al., 2015). According to (Ganesan, et al., 2018) and (Lotsaris, et al., 2021), projective AR approaches assist participants understand instructions better than printed instructions. The AR instructions increase participants' faith in Human Robot Interaction and make them feel happy while performing the activity. The robot intention and actions can be clearly observed while using AR Figure 16 and 17

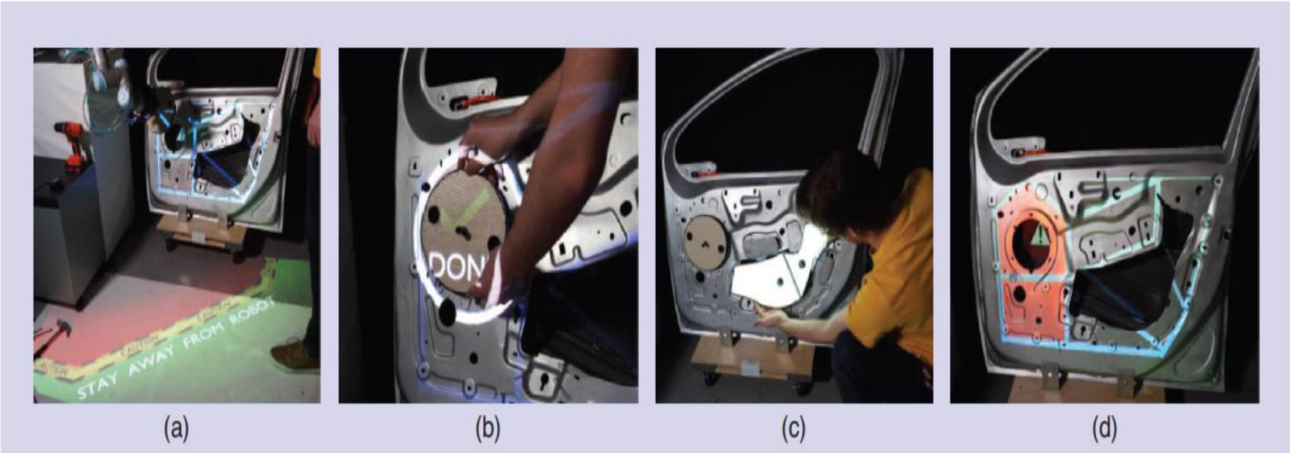

Figure 14 A set of visual cues used to signal states of the human–robot interaction, next tasks, actions, intentions, or hidden objects during collaborative manufacturing: (a) the robot work area, (b) success, (c) highlight object, (d) highlight object part (Ganesan, et al., 2018)

AR's visual signals assist workers in determining whether or not their preferred working area is unsafe. AR, according to (Michalos, et al., 2015; Ryo, et al., 2022), helps workers improve safety in a variety of ways. Through virtual demos, films, instructions lists, and images, it makes receiving knowledge for each production stage easier and faster. Visualize safety regions as well as the trajectory of the robot's end effector and receive visual and auditory warning alerts. Similarly, according to (Lorenz, et al., 2018), step-by-step maintenance instructions with supporting materials must be established utilizing work manuals and CAD data, but additional supporting resources such as images must also be created to aid in the creation of AR instructions. While, (Patrik, et al., 2018) talks about different types of optics can be used to visualize information on the AR devices and how it improves communication with workers.

A system that uses AR to view impending stages in an instruction list and the tools needed to complete the task is presented by (Cao et al., 2019). An example of providing robot information and impending instructions is shown in Figure 17. It raises awareness and makes work more comfortable while it is being done. (Gabriel et al., 2022; Villani et al. 2017) discuss the benefits of augmented reality in visualizing assembly operations in their survey papers, claiming that it will aid operators. These details are crucial in terms of the present and impending assembly processes, the average time it will take the operator to finish his or her current work, and the status of successfully completed stages against new ones (Michalos, et al., 2015; Matheson, et al., 2019). Human operators will need to be able to securely engage with the robot before they can cooperate with it.

Figure 15 Example of visualizing robot information in an work (Michalos, et al., 2015)

According to (De Pace, et al., 2018; Jost, et al., 2018; Egger & Masood, 2019; Daniel, 2019), displaying information about the robot's intentions can strengthen the cooperation system, but not only the sort of information, but also when the information must be shown, must be considered. Understanding when data must be shown is critical, since the worker must have the proper information at the right time in order to fully comprehend what the robot is doing and, as a result, feel secure. (Vogel, et al., 2017) offer a technique that creates dynamically formed safety areas by projecting them directly into the shared workstation, effectively separating humans from robots. The system displays job-related information and specific visualizations with interactive buttons, as well as an assistive area to aid and support the person at work.

Risk visualization*:* Risk visualization is a crucial idea in the use of AR-enabled technology. To facilitate safe AR work, visualization technologies, RGBD cameras, smart watches, and motion capture sensors are employed. According to (Zhihao, et al., 2020), real-time evaluation of the safety hazards of industrial collaboration robots, as well as the quantification and visualization of risk, is critical for the execution of safety measures and collaborative task implementation. The substance of the robot, the robot's own weight, tool type, operation speed, response rate, and other factors all impact the safety of industrial integrators. ISO 15066 describes several safety-related elements. While working near to the robots, AR-enabled technologies assist the worker in identifying hazardous locations. This will limit the robot's speed automatically, as speed is one of the factors that causes damage while working near robots. When a person reaches a risky zone, warnings are displayed via AR glasses, and the robot's speed is progressively reduced.

A system that after the execution of robot operations, the worker receives feedback on the Human UI and the AR glasses so as to enter the hazard zones to perform the necessary operations is proposed by (Argyrou, et al., 2018: Makris, et al., 2016). Aside from the warning indications, the human operator receives instructions depending on the work state as determined by the HRC monitoring system. When the person and robot are at a safe distance, the wristwatch allows the robot to pick up the screwdriver and complete the final run of screws. Similarly, there are many devices that helps to ensure safety with the help of AR. Figure 18 shows the risk visualization using AR where operators can interact in green zone by wearing green helmet but when obstacles enter red zone collision avoidance is activated in robot.

Figure 16 The risk visualization using AR (Liu, et al., 2020)

Another example is a solution developed by (Jost, et al., 2018) that tackles safety problems in a shared working between people and robots by providing a vest that humans may wear. The AR technology system will aid in the detection of nearby robots, even if they are concealed or moving. This assures the human's sense of safety as well as the system's inherent safety in an HRC work environment.

Training and guidance*:* Initial AR systems for assisting and teaching technicians via computer-generated instructions originate from the early 1990s (Nee, et al., 2012). Nowadays, AR has a wide range of applications in medical science, military science, automobile, nuclear science, and other fields. AR may be used to instruct personnel who are performing risky tasks (Eursch, 2007). Because maintenance, assembly, and repair jobs are often the object of learning for a user from the industry sector, the use of AR technologies for training is strictly related to them. (Yao, 2021) claims that AR assists firms in addressing a talent shortage and lowering training expenditures. It enables businesses to train their employees in a realistic environment in a more efficient and cost-effective manner. It is simple to visualize the repetition of activities and how to use the tools while executing the work. (Eursch, 2007) offer a mechanism to assist in the training of nuclear plant staff. It allows the operator to superimpose critical auxiliary information relevant to the desired job and its location directly into the operator's vision of the working environment. This feature allows for the visualization of radioactive radiation, as well as the issuing of alerts and the marking of potentially problematic locations. The technology aids in the distant and collaborative execution of the work.

Work place errors can leads to injury. Cause of errors are due to psychological well being of a person (King & Beehr, 2017). Similarly, (Sheikh, 2020) claims that fault is the reason for human error. When AR is used to perform the assembly task the mistakes are less compared with paper instructions. Time taken by the participants to complete the task is longer or shorter depends upon the familiarity of the participants with AR (Bonavolont´a, et al., 2020). Similarly in AR training platforms, construction workers can be trained with virtual materials, tools, or instructions, without being exposed to some dangerous training scenarios. Therefore, in conjunction with some other applications, such as hazard recognition and avoidance, AR has the potential to improve the safety for the construction industry (Xiang, et al., 2021; Eiris, et al., 2018; Kyjaneka, et al., 2019). Information supplied via AR appears to help close the gap between expert and nonexpert operators' performance says (Brizzi, et al., 2018). As a result, AR might aid in reducing the learning curve, allowing operators to become skilled in the teleoperation setup and so perform better after only a brief introduction to the system. In this approach, AR aids in the training of a novice worker. Similarly, (Sprute, et al., 2018) claim that AR improves robot teaching time and gives them the ability to effectively control their mobile robots in a simple way allowing human-aware navigation in human-centered environment

4.2.2 Awareness

This section discusses the concept of safety through awareness. This section delves into the principles of situational and spatial awareness, collision avoidance, and trust.

Situational and spatial awareness: Situational awareness is the capacity to notice things in the surroundings, analyze them, and predict how they will be in the near future. Similar to this, spatial awareness is the comprehension of a certain environment and situation that an operator is supposed to have when doing a particular activity. (Mazal, et al., 2019). By referring to the shared 3D views of the workplace in the AR environment, the human and robot retain situational awareness (Green, et al., 2008; Baroroh, et al., 2021). The suggested approach (Green, et al., 2008) allows robots and humans to converse and create plans in instances where the robot is unable to complete the task. As a result, the system aids in the resolution of problems as they emerge and ensures safety by revealing its internal status and goals via augmented reality. Figure 19 demonstrates how to improve safety by bringing the user's attention to the robot's movements.

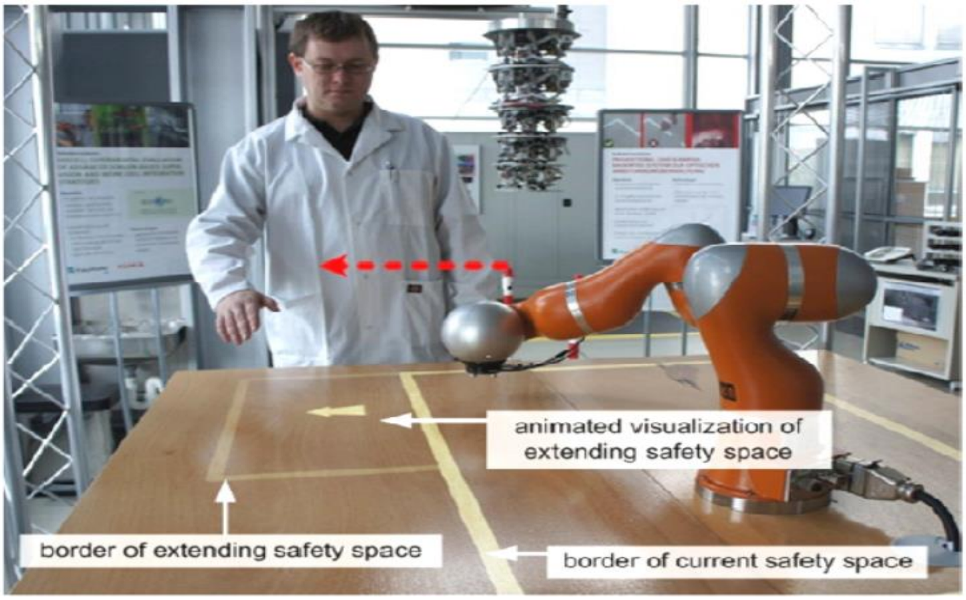

Figure 17 Planned direction of movement of robot is showed in dashed arrow (Vogel, et al., 2012)

AR technologies such as displaying 3D models when engaging with the robot boost situational and spatial awareness, which improves worker trust and cognitive capacities. According to (Chang & Hayes, 2020) and (Palmarini, et al., 2018), AR enhances the user's situational awareness. Using augmented reality to display information like robot condition, progress, and even intent would improve comprehension, grounding, and hence collaboration with sensor-equipped robots. This will contribute to an increase in human-robot trust. (Vogel, et al., 2017) suggested a system based on projection-based sensor model AR technology, which requires no new sensors yet provides situation awareness while also lowering the overall system cost. Not only does the technology minimize complexity, but it also enhances collision avoidance and human-robot interaction. Similarly, (Wei, et al., 2022) claims AR technology enables operators share the common visual guidance adjusted based on their position and orientation in AR-aided collaborative assembly, improving the awareness of the current assembly tasks intuitively using HMD-AR.

According to (Green, et al., 2008 ; Green, et al., 2008b) AR enables an exo-centric perspective of the collaborative workplace while also providing spatial awareness. Augmented reality technology is utilized to promote natural motions and give a shared 3D spatial reference for both the robot and the human, allowing communication to be grounded and spatial awareness to be maintained. This contributes to a more optimum working environment for humans and robots. The capacity to deliver rich spatial signals, egocentric and exocentric points of view, and egocentric and exocentric points of view helps to boost spatial awareness with AR. According to (Green, et al., 2008) the if a robot does not grasp the orders issued by humans, this allows it to obtain extra information. With the aid of AR, it is possible to see what more information is required to carry out the activities. This will aid in improving communication and reducing misunderstanding in the workplace for both humans and robots. In this way, proper communication between people and robots is formed. (Frank, et al., 2016) discover that cooperatively executing object manipulation tasks with the robot is simple and pleasant using AR. The suggested architecture enables users to utilize their mobile devices to issue instructions that are sufficiently accurate to allow a sensorless robot to undertake precise object manipulations with the use of AR with little to no training.

Collision Avoidance*:* According to safety requirements of industrial robots, robotic systems must be used which can actually detect or prevent a collision (Sebastian,, et al., 2018). In a variety of methods, augmented reality increases collision avoidance and predictability. The safety-related approach for human-robot collaboration, according to (Liu, et al., 2020), may be separated into two key directions:

collision detection and collision avoidance. The torque sensor is primarily used by the former to precisely identify the incidence of a collision or contact, allowing it to respond afterward. The latter use some form of sensor to continuously monitor the workspace and react in front of collisions to avert collisions. According to (Liu, et al., 2020) the robot's path and movements are displayed in augmented reality, allowing people to anticipate and avoid collisions. AR allows robots to stop when they come into touch with an impediment, with response times that allow for safe collaboration and avoid injury to the worker.

The robot can anticipate a likely collision and must come to a halt and wait for clearance (Vogel, et al., 2017; Bolano, et al., 2021; Guhl, et al., 2018; Jost, et al., 2018; Bolano, et al., 2017) claim that AR makes it easier for people to engage and enhances their trust and ergonomics while doing so. A human with no prior understanding of robotics may use gestures and vocal communication to adjust the paths of robots and interpret collisions. By discussing and reviewing a strategy with the robot prior to execution, it is also feasible to increase spatial and situational awareness via AR. The usage of augmented reality can assist the human worker in swiftly determining whether the robot needs to adjust its movements, as well as making him informed of the robot's present purpose. This is beneficial in reducing the danger of the new robot plan being blocked. It can also assist the user in determining the condition of the parts by indicating those that require human intervention. The users felt more at ease and confident in the interaction as a result, and the anxiety created by the robot's lack of knowledge was reduced. Figure 20 depicts a collision avoidance method in which the robot arms shift to the right to avoid colliding with the human hand.

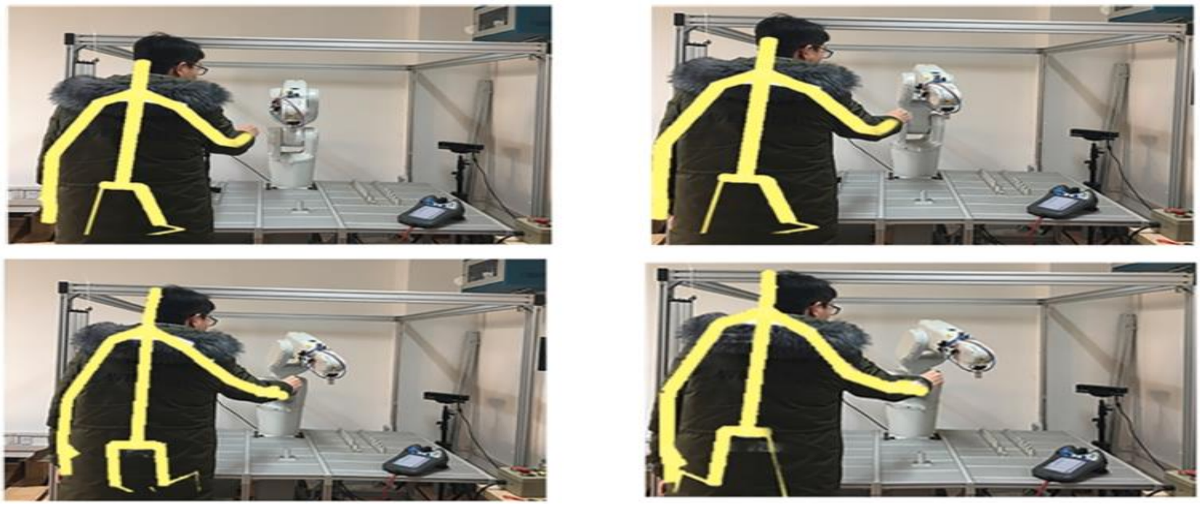

Figure 18 Collision avoidance process (Liu, et al., 2020)

Similarly, the use of AR to enable contactless robot operation, which is beneficial for safe working inspection jobs and operation in tough settings (high voltage, acid, sharp pieces) (Strazdas, et al., 2021). The gesture-based, contactless technique promotes the user's safety by avoiding physical touch between the human and the robot. In this case, the robot comes to a halt before the collision because a virtual collision occurs beforehand, allowing it to safely avoid hitting humans. Another example, a system that enables workers in a human-robot collaborative environment to interact with a robot while also receiving information about the robot's state and plans that are relevant to the human's safety and trust, such as the robotic arm's intended movement or the mobile platform's navigation plan in which AR can assist to avoid collisions in a setting where numerous workers are working (Tsamis, et al., 2021). In an HRC workplace with numerous employees, AR can assist identify collisions in this way.

The use of augmented reality in industrial settings might help to reduce accidents caused by human error. Their approaches raise human awareness of hazards by delivering visual clues about possible danger in the robot's workspace for each activity and analyzing qualitatively the collision threat in various locations of the robot's workspace using augmented reality. (Michalos, et al., 2014: Hjorth & Chrysostomou, 2022: Makhataeva, et al., 2019) states ways to ensure safety during HRI is to restrict the kinematic and dynamic properties of the robot motion at all times such that accidental collision does not cause harm. As a result, ISO10218 standard introduced several requirements. At least one of these have to be satisfied to establish safe HRI in an industrial environment accorinding to the authors.

Trust: The main factor for a successful HRC, according to (Palmarini, et al., 2018; Andronas, et al., 2021; Qiu, et al., 2020) is trust. They presented a technique for boosting trust in an HRC setting. AR will improve comprehension, grounding, trust, and hence collaboration by displaying information such as robot condition, progress, and even intent. One of the important determinants of trust in HRC is context awareness and safety (Palmarini, et al., 2018). Context awareness enhances human perceptions of safety, increasing trust in HRC. Similarly, using AR to comprehend cobot motions in the actual world has improved safety while cooperating with the cobot, increasing trust. Figure 21 shows the ways of improving trust in HRC by awareness and planned motion of robots using AR.

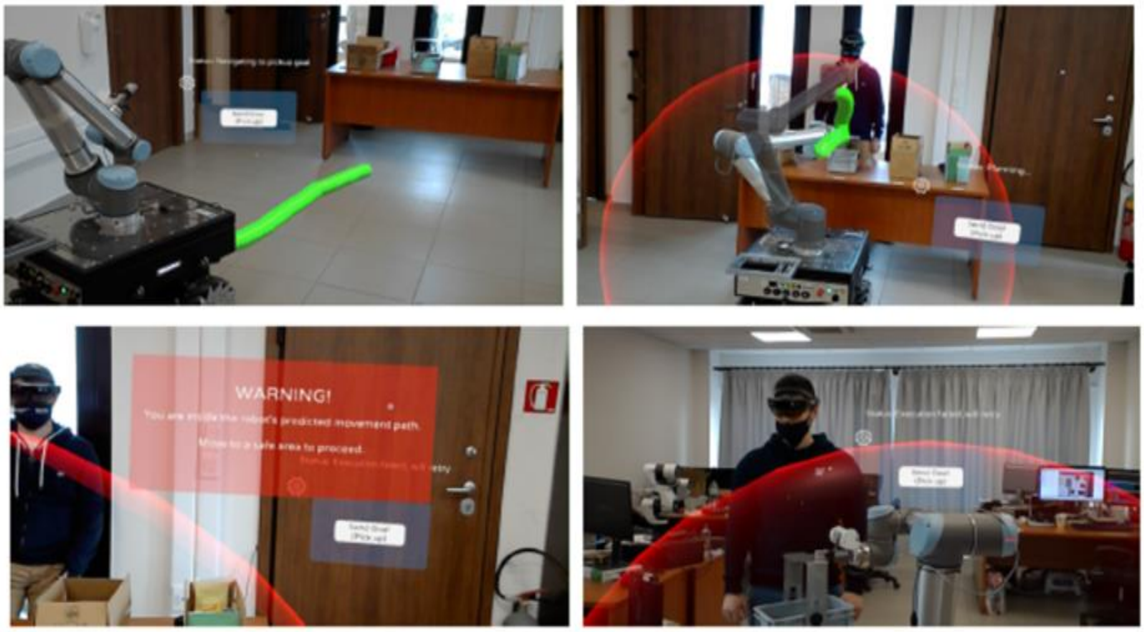

Figure 19 Augmented reality visualizations through HoloLens: (a) Planned navigation path of the robot as sequence of green 3D spheres; (b) Planned manipulation movement for grasping as sequence of 3D spheres and robot workspace as semi-transparent red sphere; (c) Warning message displayed to user in case of detected potential collision with the robot workspace; (d) View of a detected potential collision from another user's perspective (Tsamis, et al., 2021)

(Hald, et al., 2020; Simoes, et al., 2021) discuss the relationship between speed and trust. It has been discovered that when the speed of the robots is raised abruptly, the operator's faith is eroded. However, it is also reported that when people use or engage with the robot for an extended length of time, confidence is restored. (Bolano, et al., 2021) (Tsamis, et al., 2021) they found that when using AR technologies for communication and visualization, user satisfaction, perceived safety and trust, as well as the required time to complete manipulation tasks were all faster than when using other traditional methods like tablets. With AR, adequate communication is maintained, and the user is able to comprehend the robots' courses and plans. This improves the user's trust, sense of safety, and awareness in HRC. Similarly, (Andreas, et al., 2021) states that AR may be the enabling technology to enhance trust and acceptability in autonomous automobiles, such as aiding in the transition from manual to automated driving. In circumstances when human operators are not kept informed about the robot's internal state, their faith in industrial manipulators may diminish, threatening human-robot collaboration. As a result, new methods for managing and addressing robot concerns are required. This is where the use of augmented reality comes into play. Faults can be clearly apparent on virtual

Graphical User Interfaces (GUIs) or on the manipulator itself, allowing users to be quickly informed of the internal robot's status (Giancarlo, et al., 2019).

4.2.3 Ergonomics

This section covers themes related to how AR enhances ergonomics. Cognitive and physical ergonomics are intertwined in ergonomics. Stress, anxiety, perception, confidence, mental load, contentment, experience enhancement, comfort, choice of options, acceptance, and mistakes are all considered cognitive qualities in this study. Physical load/effort and operator mobility are also included in the physical ergonomics area.

Cognitive ergonomics: The cognitive burden encountered by human operators may be minimized using various AR enabled technologies such as projection-based AR. Operators may quickly view instructions and information using augmented reality, which improves the user experience and reduces job completion time. (De Pace , et al., 2020; Makhataeva & Varol, 2020). While, (Villani, et al., 2017; Egger & Masood, 2019; Michalos, et al., 2018; Gabriel, et al., 2022; Baroroh, et al., 2021; Sim˜oes, et al., 2021; Bottani & Vignali, 2019) in their surveys states the advantages of AR for improving ergonomics. They all agree that AR improves operators' feelings of safety, acceptability, and comfort when working near industrial robots by bringing simple and user-friendly tools and decreasing the cognitive burden of assembly procedures by splitting the effort between them and the robot.

According to (Gianni, et al., 2013), motion planning using AR increases perception between robots and people by providing input on the courses that robots aim to take. Humans will benefit from this in high-risk tasks such as rescue planning. According to (Bolano, et al., 2021; Makris, et al., 2016), combining AR with other smart technologies such as a smart watch allows for better feedback while working with robots. The instructions to the robots may be communicated via new current technologies, eliminating the need for operators to travel to the system every time they want to make a modification. When a crisis arises, this will lessen their worry and anxiety.

When compared to other traditional methods of communication with AR (Tablets, Monitors), (Chacko & Kapila, 2019; Hietanen, et al., 2020) claim that AR interface is user-friendly and intuitive to operate the robot, and it allows users to easily communicate their intentions through the virtual object. (Hietanen, et al., 2020) shown that a user experience study revealed that HoloLens-based AR is not yet suited for industrial manufacturing, but a projector-based AR configuration demonstrates clear benefits in safety and job ergonomics. When compared to the Hoolens, workers find it easier and more comfortable to operate with projection-based AR.

The advantages of projection mode AR over printed and mobile display techniques to human communication are also stated by (Ganesan, et al., 2018). When people work with robots using AR, the author claims that errors, mistakes, and job completion accuracy are higher than when humans collaborate with robots using other ways. According to (Luipers & Richert, 2021), seeing robot motions reduces stress while doing the activity, and the system may compute the ergonomically most beneficial posture for the human-cobot handover using Kinect RGB-D cameras and joints. (Luipers & Richert, 2021) accomplished this through the use of motion visualization and augmented reality to track assembly status. To complete a handover, the visible robotic hand moves to the user-specific ergonomically ideal posture. This handover posture relieves pressure on the human joints, improves the user experience, and improves HRI. Close human-cobot interactions and cooperation will become more acceptable as a result of this. Figure 22 shows working steps of the cobot and the assembly status visualized in AR. The joints of the human are drawn in orange and are tracked to realize an ergonomic handover task.

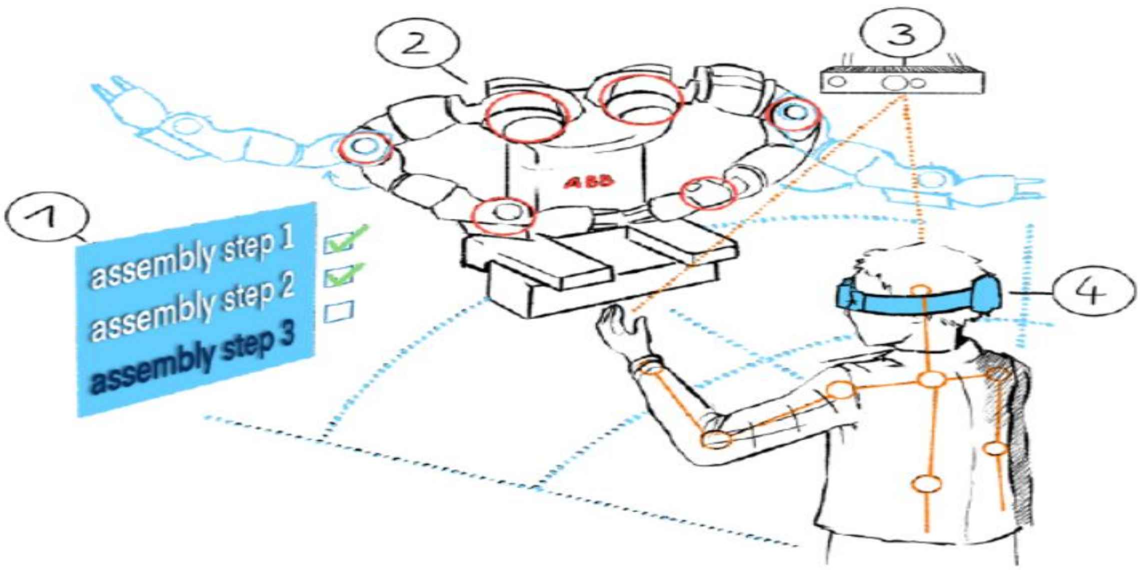

Figure 20 Motion visualization using AR. Steps 1: finished and unfinished assembly steps, 2: YuMi cobot (ABB, Switzerland), 3: Kinect camera, 4: HoloLens glasses (Luipers & Richert, 2021)

The importance of visualization in improving the ergonomics using projective and HMD is discussed by (Vogel, et al., 2020) (Eursch, 2007). This comprises details such as missing or incorrect parts, hardware/software faults, robot trajectory schedules, statistics, and the completion of a project. As a result, the visualization system not only improves operational availability by reducing inadvertent safety zone violations, but it also improves the usability and ergonomics of the entire workstation. This capability allows for a considerable boost in job safety, for example, by visualizing hazards, issuing alerts as needed, and marking hazardous regions. An AR-system provides all required information to operators, allowing them to cope with their assignment, make better judgments, and so minimize stress and boost comfort, allowing them to do all tasks at once.

A system in which virtual context-based information is delivered to the human via AR by overlaying the information in the perceived real-world environment is suggesyed by (Jost, et al., 2018). Smart glasses are utilized to allow this procedure to visibly project information over real-world items of interest in a perspectively accurate projection. When working on activities like choosing, navigating, and maintaining, deliberate involvement is feasible, and cognitive fatigue may be avoided. (Jost, et al., 2018) claim that workers may not be able to grasp what occurred to the robot if a defect develops on a manipulator, since its motions are abruptly stopped for security reasons. As a result, because the operators are unaware of what is going on in the manipulator's controller, their stress and anxiety levels may rise. The user can readily grasp robot movements and aim with the use of AR, which is beneficial in identifying robot defects. This increased the users' comfort and trust in the conversation while reducing the fear produced by the robot's lack of information (Bolano, et al., 2017; Giancarlo, et al., 2019).

An experiment to demonstrate that AR is more comfortable for carrying out various tasks with robots, where task execution using a collaborative setup and the AR device requires less physical and psychological strain than the manual method is conducted by (Lamon, et al., 2019). Participants in the studies also revealed that their perspective caused them to be happy with the suggested collaborative approach, despite the fact that the work was more difficult to complete in the manual configuration. Whereas (Materna, et al., 2018) offered an experiment to decrease mental burden and attention switching by focusing all interaction in a shared workspace, mixing several modalities, and allowing engagement with the system without the use of external devices. All participants were able to adjust the robot's software to their ergonomic demands and had a positive AR experience.

Physical ergonomics: Repetitive and force-demanding assembly jobs are one of the risk factors for human health in industrial situations. Awkward postures, applying high pressures to complete a task, using heavy or vibrating instruments, and pushing on hard surfaces are only a few examples of probable occupational causes of tiredness, discomfort, and injury (musculoskeletal diseases). (Michalos, et al., 2015) presented a method that assists assembly workers in reducing physical effort. The technology aids the operator in visualizing how to carry out the assembly operations. Figure 23 uses augmented reality to visualize the robot's operation and operator instructions (text and 3D model). This will make it easier for the operator to complete the operation without making mistakes or injuring themselves. While the human performs sensitive duties (cable assembly), the robot transports the heavy goods without colliding with the person. The program may be used with AR glasses by the user. In addition, depending on the stage of manufacturing, the user can see many assembly models.

Figure 21 Showing assembly actions and instructions using AR (Michalos, et al., 2015)

An AI system that detects the actions made by operators within a human–robot collaboration cell suggested by (Nikos, et al., 2021). According to the suggested paradigm, the human takes the lead, while the robot provides non-intrusive assistance by bending its behavior around him or her. Muscle strain is reduced to a tolerable degree by the system. Similarly (Quang Huy, et al., 2017) presented a projective AR-based system that might be used for outdoor industrial operations. the system will allow the elimination of mouse and keyboard or teach pendants in industrial contexts. For controlling the system, a prototype with five haptic buttons matching to five fingers was built and assembled. It's also worth noting that the gadget allows the primary user to operate it with just one hand, significantly improving the operator's safety during an industrial operation. In a similar vein, (Hietanen, et al., 2020) shown that, of all AR-enabled technologies, Projective AR is the best for engaging with humans, compared to HMD and traditional methods (Tablet, Monitors).

4.2.4 Communication

This section covers themes related to how AR promotes safety through communication. Aspects of communication include both verbal and nonverbal communication.

The significance of communication in HRC is discussed by (Chang & Hayes, 2020; Green, et al., 2008; Hjorth & Chrysostomou, 2022; Dianatfar, et al., 2020) in their surveys. AR technology allows a human to share an ego-centric vision with a robot, allowing human and robot interactions and intents to be grounded. Exo-centric views of the collaborative workplace are also possible, allowing for spatial awareness. AR technology may thus significantly aid human-robot collaboration systems, not only because it provides visual signals that improve communication by allowing the human to better understand what the robot is doing and its objectives, but also because it combines speech (spatial dialog), gesture, and a shared reference of the work environment, making collaboration more natural and effective.

Verbal and non verbal communication*:* In an automotive case study, (Christos, et al., 2018) presented a system that uses augmented reality and hand-held smart watches to engage with robots. Through that mechanism, several types of communication are conceivable. According to the authors, employing audio instructions through smartwatches allows the operator to pause the scenario execution in order to fine-tune the robot's movement to the operator's comfort. In contrast, (Lotsaris, et al., 2021) presented a method that allows for direct commands to be sent to the robot platform. The user may move the robot right away by pointing to the desired area. To complete the calibration procedure, the user merely has to glance at the code and execute an AirTap motion. Working with a robot in this manner is done without any contact, which promotes safety. Figure 24 shows the different functionalities available in smartwatch that helps to collaborate with the robot.

Figure 22 Different functionalities in smartwatch (Chang & Hayes, 2020)

According to research, successful communication between the robot and the human may be achieved by giving the human with a shared perspective of the robot's workplace and allowing the human to utilize natural speech and gestures (Green, et al., 2008a; Green, et al., 2008b) . By clearly exhibiting the robots' objectives in this shared workstation, common ground may be quickly found. Similarly, (Strazdas, et al., 2021) developed a system that uses contactless communication to increase HRC safety (hover and hold gestures). Because there is no requirement for depth movement, the hover and hold approach method varies from most standard UIs (hover and click/touch).

Some users sought to push a button/object and expected the system to respond to varied depths of pointing/clicking movements. As a result, this technology outperforms other communication methods. While (Zhenrui, et al., 2021) introduced a more advanced technology for human-robot interaction using a brain-computer interface that could record the user's brain activity and translate it into interaction messages (e.g., control commands) to the outside world, allowing for a direct and efficient communication channel between humans and robots. The results demonstrated that, when compared to the hand gesture-based input technique, the suggested eye blink-based approach can minimize user input time, potentially improving the efficacy of human-robot communication.

Overall, the application of AR to the industry sector is significant because it considerably enhances communication in product design and production development: it aids in the early detection and avoidance of design faults, decreases the number of physical prototypes, and saves time and money for businesses. In many industrial applications, augmented reality is seen as a beneficial tool for enhancing and speeding up product and process development.

4.3 Summary of literature review

The most important aspect of employing AR technology to improve safety is visualization. Humans have the ability to visualize information and instructions that will assist them in completing the activity without injury or errors. Humans may build a safe HRC environment and decrease robot collisions by visualizing the danger. Similarly, AR aids employees in training, with results indicating that AR training enhances worker safety and reduces mental strain during task execution. The second idea is that of awareness. AR enhances spatial and situational awareness, enhancing safety. Collision avoidance and prediction using AR not only increases safety and trust, but also decreases accidents.

Physical and cognitive ergonomics are both improved by augmented technologies. AR-enabled technologies allow users to engage with robots without using their hands, reducing physical contact with robots and improving safety. Similarly, when directions and instructions are given to the operator in a more realistic manner when doing jobs, the mental burden is lessened. The final idea in which AR is used to increase safety is communication. AR allows users to engage with robots without touching them utilizing both verbal and nonverbal communication.

5 Case study

In this chapter, the case study is presented. The implementation is described as well as the analysis of this research

5.1 Implementation

For the interview, three businesses have agreed to participate. For the interview, six firms were contacted. For the time being, three firms' interviews have been completed due to the frequent extension of dates and cancellations of interviews. The case study's three participants are all Swedish businesses. In the field of combustion engines, two companies are active. A manager or an engineer from each organization was interviewed. In both companies that deploy collaborative robots and those that do not, interviews are done. In the interview, they discuss their AR and HRC expertise and knowledge. Similarly, due to the current state of affairs, finding firms that employ AR has proven to be tough. As a result, none of the enterprises surveyed employ AR in their operations. As previously stated, the literature review provides the foundation of this study, with interviews serving as a supplement. The Table 3 shows the details of the companies.

Table 4 Company details

Manager Number	Manager 1	Manager 2	Manager 3
Role of the person	Maintenance manager	Maintenance Manager	R & D manager
Company main activity	Manufacturing combustion engines	Manufacturing and assembly of engine and other parts	Manufacturing machines and installation
Use cobots in works?	No	Yes	Yes
Experience in HRC	No	Yes	Yes
Experience in AR	No	Yes	Yes
Promote AR and HRC	Yes	Yes	Yes

The interview questions are based on the results of the literature research. The interview questions were organized in interview guides, (Appendix E and F) where they were categorized by topic areas and accompanied by follow-up questions. For the company interviews, two interview guidelines were created: one for firms with AR and one for companies without AR. Throughout the process, the interview instructions were modified. Before each corporate interview, background research was conducted on the firm, including its main activity and personnel number, as well as the individual, including job title and position within the organization. Each respondent was told about the purpose and ethical issues before to the interview. Confidentiality and anonymity were discussed, as well as voluntary involvement with the option to withdraw at any time and informed permission (Appendix G). Before the interviews, the material was presented orally and on an information sheet that was emailed to the participants. Zoom was used to record all of the interviews that were performed through video conference. The participants were asked if they agreed to be recorded, and they all said yes. There were also notes taken. Following that, each participant was asked for permission to be contacted again if any other questions arose, and everyone agreed.

5.2 Analysis and results

As previously said, the literature review is the most important aspect of the research, while interviews are supplementary. Because transcription of interviews is time consuming for this study, interviews are not transcribed. Rather, the interviewees' replies are recorded and discussed. As a result, with the use of recorded data, notes are obtained from interviews multiple times. In terms of visualization, ergonomics, awareness, and communication, all participants believe that AR may increase safety in HRC situations. The major topic of discussion among the participants was the safety of AR through visulaisation, which was also the main theme of the literature study. Manager 1 has no past experience with augmented reality, but based on what he has learned, he feels that augmented reality is a good fit for increasing safety in a collaborative setting.

5.3 Discussion on case study

Visualization is the biggest category talked among the four category by all the managers. Managers think that visualization is the most important idea for increasing safety in an HRC workplace utilizing AR, and that it encompasses all other categories like as ergonomics, awareness, and communication. As a result, rather of focusing on subcategories, an overarching topic about visualization is explored.

“However, really collaborative production is still uncommon. No one in this study's firms does so, and the researchers claim that the technology isn't yet ready for it” (Schnell, 2021). Similarly, in the authors research states that despite the fact that collaborative robots appear to be the way of the future for SMEs (Small- Medium Enterprises), there are still numerous obstacles to overcome in order to discover flexible, smart, quick, and secure solutions.

"I believe that you may occasionally feel compelled to approach the robot to see what is truly going on. However, because there are barriers in the way, you can occasionally see exactly what's going on at specific spots. And it would be a better that will be better with collaborative robots to go closer to, to the parts and observe what's actually going on when there's a problem, which is typically the case." (Manager 1)

Manager 1 is employed for a firm that does not deploy collaborative robotics or augmented reality. The industrial robots that are utilized in the firm are kept inside the gates that are used to lift heavy equipment such as engines. When the operator opens the robot's door, the robot will stop and the operator will be able to operate safely. The only physical barrier used to keep humans and robots apart is fences. Manager 1 mentioned the difficulty of working with industrial robots when they are put inside fences, making it impossible to visualize what the robot is actually doing. Manager 1 proposes that collaborative robots be used to solve the problem. According to the manager, this is only valid while dealing with smaller tasks.

"You could demonstrate workers how the machine is meant to move in the early phases of construction, using technologies AR and yes, maybe in that way." (Manager 1)

Manager 1, who has no expertise with augmented reality, believes that during the early phases of machine construction, new technologies such as augmented reality can assist in showing workers how the machine truly works. When compared to voice and writing, seeing the movements in real time helps workers better understand the task. Tasks ranging from carrying little equipment to large equipment are all part of the combustion engine manufacturing process. AR might aid workers in determining which tasks are appropriate for them and require the least amount of effort.

"If we could have a tool, perhaps a digital representation of the assembly station, for example, that we could deliver to production. Then they may combine it with other tools to program the robot's course, for example, which might be a significant step ahead. So, in a summary, tools that make implementation easier. As a result, you don't need all of the talents to cover all of the safety standards." (Manager 2)

Manager 2 is employed by a firm that employs both collaborative and conventional robots. He has worked with technology such as augmented reality, although the company where he presently works does not employ it. He argues that AR makes it simple to create items by viewing a 3D representation of an assembly station. It enables workers to alter production lines by doing tiny tasks using all necessary instruments while adhering to safety rules. This will allow workers to work autonomously and make adjustments to collaborative robots, such as altering position. However, a safety tool such as AR is required to compute all of the safety parameters and inform the workers the safety precautions or how safe the new position is to work in.

"I believe that augmented reality will be a significant tool in the future. To that end, we supply all of the tools required for production to do simple automation. At the very least, I believe they must be less expensive, quicker, and more effective." (Manager 2)

Manager 2 believes that augmented reality is the finest tool for simplifying automation. Even if AR is not employed in his firm for safety reasons, it may be a valuable tool in the future if basic automation becomes necessary. Manager 2 also claims that businesses choose to employ AR and HRC based on the application's applicability than than focusing on completely collaborative work.

Manager 3 works for a company that manufacture and implement robotics sometimes directly to the customer or stop here at our place, and then we install it. For example like collaborated robots and vision camera. Since they manufacture and install machines to different companies they receive a lot of feedback from their clients and these informations supported not oly for collecting information but also helped a lot for validating the interview data.

"AR and collaborative robots can helps to update factories to smart factories" (Manager 3)

Manager 3 also believes that AR may help employees in the workplace by displaying safety factors while performing collaborative tasks. Manager 3 believes that, with the use of augmented reality, factories can be automated into smart factories that can control the entire process with fewer laser scanners and cameras in the future. The participant also claims that AR aids workers in anticipating accidents and taking proper measures in response.

5.3 Summary of case study

Participants are positive about the use of augmented reality to improve safety in a collaborative setting. When it comes to AR in terms of safety, the key category mentioned by all participants is visualization. Participants agree that AR and HRC are the future of automation, however there are certain implementation issues that will be covered in the following chapter.

Ethic and Quality of research: In conjunction with the interviews, the concept of informed consent is vital, which implies that participants should understand exactly what the aim is, how the information will be used, and their right to withdraw and not participate. If the responder is compelled to participate in the interview by a superior, this might be an ethical issue. That is why informed consent is critical, so individuals are aware of their right to withdraw at any time or not participate at all if they so want, both vocally and in writing. Similarly, in this study, anonymization will be important, but it will also be a balancing act between anonymization and the narrative, which will include instances and citations. Personal and individual data is an ethical concern in qualitative research. After a year with Covid 19, many individuals had become accustomed to video conferencing, and practically all interviews have to be performed virtually rather than in person. This might have influenced the case study's conclusion since a video conference or phone contact lacks context, but a personal visit could provide a better grasp of the robot's environment and surroundings. It is easier to notice the respondent's body language and gestures in a physical interview, and it is also simpler to build a better contact by having the opportunity to small chat while taking a tour of the manufacturing area and establishing some type of relationship before the interview (Schnell, 2021). Validity does not have the same implications in qualitative research as it has in quantitative research (Creswell, 2014). Qualitative validity refers to the correctness and dependability of data obtained via the use of certain processes. The correctness and systematics of the technique selection, data collecting procedure, and analysis will hopefully be a strategy to assure validity in this study. Because of time constraints, interview analysis may not be done in a systematic manner; yet, as previously stated, interviews are helpful. They are used to knowing what is actually happening in the real world. According to (Gibbs, 2018), even if notes will be taken and the content may need to be reviewed numerous times, it is not required to transcribe the information if the focus is on the larger picture.

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6 Results and discussion

The outcomes of the literature review and company interviews are compared and triangulated in this chapter. The research issue is addressed, recommendations are offered, and the paper concludes with a summary and discussion. In both the literature and the companies, the major category for enhancing safety utilizing AR in an HRC workplace is the same. The literature identifies visualization as the most important category, and interview participants agreed. AR increases HRC safety through visualization, ergonomics, awareness, and communication, according to all participants. Despite the fact that the findings of the literature study and interviews show that AR improves safety, there are several obstacles and gaps between the results gained and the real-world use of both AR and HRC.

Despite the fact that all participants think that AR may enhance safety HRC in many ways, both technologies have certain limits. Research based on AR and HRC is growing and yielding numerous benefits, however in the actual world, HRC and AR are not widely used in industry. Incorporating collaborative robots and augmented reality into industry faces several hurdles. As a result, the results of the literature study look different from those of the case study. When it comes to research, both technologies have several advantages, but in practice, collaborative robots are uncommon, and augmented reality is rare for safety applications. Figure 25 depicts the key challenges for deploying AR and HRC in sectors based on interviews.

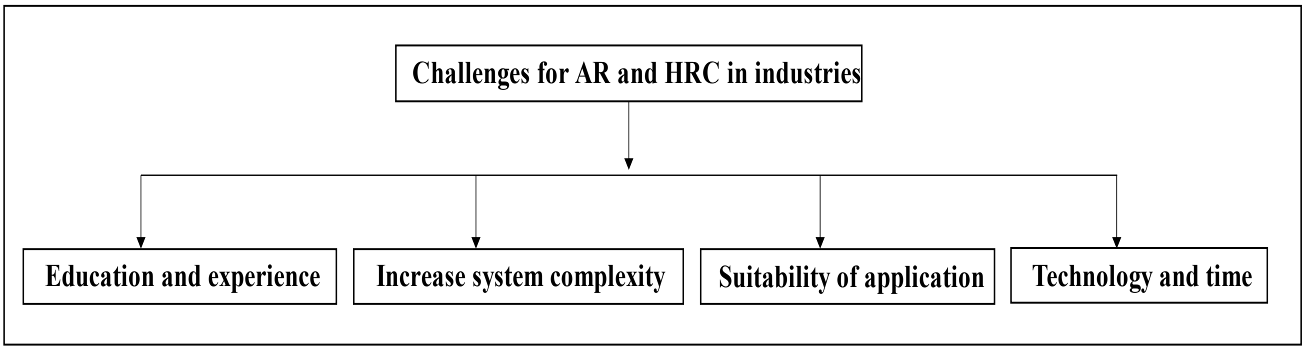

Figure 23 Challenges for AR and HRC in industries from interview

Education and experience: One of the reasons why HRC and AR aren't widely employed in industry is that workers require greater knowledge and abilities. According to Manager 1, *" It is also a matter of education; if people could see and test a collaborative robot, they would become much more comfortable with it and it is mostly about safety."* Safety fences and typical robots that stop functioning when a person enters the fence are more familiar to operators and supervisors. When working near to a collaborative robot, the operator needs have greater abilities and expertise. According to (Moeuf, et al., 2020) SMEs are more at danger from Industry 4.0's lack of knowledge since they typically lack the skills necessary to perform support services. It was expected that professionals would have strong opinions on this subject given that Industry 4.0 makes use of cutting-edge technology and demands a wide range of skills. Manager 1 also notes that if collaborative robots are introduced, we will need to work closely with and with the production employees to demonstrate that it is challenging, but safe, and that they must feel safe working near the robot. Otherwise collaborative robots are difficult to implement. (Andreas, et al., 2021:Palmarini, et al., 2018) states trust and acceptance of workers are important factors to considered when working close to the robots. According to (Olender & Banas, 2019) properly trained staff members are another approach to allay employees' fears of robots. Operators in Company 1 are more at ease and are unaware of HRC, thus education and training might help them gain greater understanding and trust in collaborative robot. .

Manager 1 claims because robots are confined behind gates, basic automation is the best to execute because it requires less expertise and understanding about safety. Manager 2 further claims that integrating HRC and AR for safety purposes necessitates highly trained workers with a thorough understanding of both safety and productivity. Changing the robot's location and calculating safety parameters, on the other hand, make the work more complicated. Similarly Manager 3 also states that *“In today's world, practically everything is done with tablets and smart phones instead of paper instructions. As a result, personnel must gain expertise and adapt to new technologies that help for its and their future”.* One of the challenges for AR and HRC on industries are education and experience. Operators should have an idea about the system and how it works and for that companies should implement them and them need to work with it and get adjust to it. The adoption of collaborative robots has been cited as requiring both technical education and management-level training in areas such as technology advantages awareness and employee-level technical education in areas such as functional comprehension (Calitz, et al., 2017).

Increase system complexity: According to Manager 2, implementing collaborative robots is complicated in and of itself, therefore incorporating AR in HRC will make the system much more complicated. *“Traditional automation is purchased from integrators; collaborative automation must be completed in-house; otherwise, the cost would be unaffordable. When we implement it in-house, we'll need more tools to simplify and validate safety, among other things”* says Manager 2. (Kumari

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& Nitish , 2018) states that dedicated hardware needs, the necessity for less expensive technologies, and security issues are a few difficulties AR deployment faces. The more money that tech businesses invest in these technologies and provide for them, the more new developments, adaptations, and experiences will be made feasible. This problem may be solved by continuing to create and release more and more items into the open market. Manager 1 asserts Simple automation is the easiest to adopt, and industrial robots are more comfortable than collaborative robots since they require less time, tools, and understanding about safety because robots are confined behind gates. In practice, this makes HRC difficult to employ in industry.

Manager 2 also claims that businesses are pushing for simplified automation, and that projects are underway to figure out how to achieve so. Manager 2 also believes that AR may be a tool that focuses on easy implementation and allows a single operator to perform all tasks, including robot programming, calculating safety parameters, and modifying robot position in the future. It is currently not practicable owing to the very high abilities required in terms of both safety and programming. Similarly, AR and HRC are difficult to adopt since there is a lot of backend work to be done before they can be used, such as risk assessments. It will also take a significant amount of time, effort, and money, making it more challenging says Manager 3. (Sebastian, et al., 2018) states that the construction of a safe HRC system typically involves significant financial risks, and high risk requirements are established. This avoids having to put in a lot of effort to find out what potential there is. The integration of a traditional HRC system can be made more challenging by unusual boundary circumstances, such as warm ambient temperatures and very flexible materials. So it is not possible to plan an HRC system with little effort

Suitability of application: All three participants have unique perspective on the usage of collaborative robots in an industry, depending on the application's suitability. Collaborative robots are unable to move such big equipment since both firms manufacture combustion engines and associated parts. Collaborative robots, they feel, are best suited for simple automation, minor repetitive activities, and lifting small equipment. Manager 2 reports that the participant visited a number of companies in the business, with one of them having 35 or 40 distinct robots in production. They failed to mention that none of the replies were collaborative in nature. It is still rare to work truly collaboratively, though. No one of the companies in this study does so, and the researchers state that the technology is not ready for that yet. Despite the fact that the operator was near by but did not collaborate. Manager 2 and Manager 3 claims that robots meant for collaboration are employed for cooperation rather than collaboration. According to (Sebastian, et al., 2018), robots capable of cooperation are only employed to carry out automated tasks without the usage of a protective barrier. According to robot manufacturers, system integrators, and HRC users, finding a suitable workstation is the largest problem. The HRC users in their survey reported having trouble locating workstations for productive collaboration since there aren't any established standards or procedures (Gaede, et al., 2019) .

Manager 2 and Manager 3 recommends that companies concentrate on application and appropriateness rather than collaboration. Manager 2 further claims that using AR not just in HRC applications, but also in other areas of industry, would assist to boost AR's adoption in the workplace. Because companies will not invest a significant amount of money on a single application. Companies will use AR if it can be utilized to increase safety in the HRC environment in conjunction with other applications in production, assembly line, and easy robot installation. We may also be able to deploy the robots in additional sites if the technology is simple and the robots are economical. It will be costly, though, if they take a large amount of work to install. Manager 3 also support this statement for collaborative robots by giving an idea of *"Reuse of robots"*. Using the robots for different applications inside the industry like manufacturing, production and assembly will helps to increase their usage and helps the company to make more money. We may also be able to deploy the robots in additional sites if the technology is simple and the robots are economical. It will be costly, though, if they take a large amount of work to install. (Olender & Banas, 2019) states that while there are no set rules, protocols, or stages when it comes to the adoption in a company, robot solutions take a lot of work. Similarly, (Fast-Berglund and Romero 2019) claims that many companies lack the knowledge and need a defined robot and automation plan for a successful cobot adoption. They also frequently select automation activities that are overly complicated and need excessive amounts of engagement.

Technology and time: Another issue that AR and HRC in industries encounter is technology and time. As previously said, it will take time for individuals to adjust to new technology and become used to them. Future engineers and operators should be taught and trained in these technologies so that they might be promoted in the future. In that situation, businesses should put them in place after conducting an acceptable risk assessment and determining their acceptability and application. (Gaede, et al., 2019) states that risk assessment is cited as one of the major obstacles to HRC implementation, along with the application of relevant safety standards, a lack of internal expertise, and the absence of useful guidance. Similarly, the installations of collaborative robots require highly complex risk assessments. According to (Moeuf, et al., 2020) one of the risks noted is the rapid advancement of technology, which raises the possibility that an investment in technology could become obsolete. In fact, another more effective (or the same but superior) piece of technology may already be in use by rivals by the time the chosen technology is fully adopted and mastered.

(Hietanen, et al., 2020: Xiang, et al., 2021: Quang Huy, et al., 2017: Gabriel, et al., 2022) state that projector mode AR is more comfortable to use than HMD-AR. Because of its ergonomic issues, HMD-AR is difficult to use for lengthy periods of time. In comparison to projector mode AR, HMD-AR seems less secure, weighty, and uncomfortable. Its shortcomings include weight and eyestrain, making it rather difficult to use for extended periods of time. Additionally, it has been shown that HMD-AR instructions and information can be confusing and even block some views. As a consequence, it is discovered that projector mode AR is simpler to use than HMD-AR. Although it is only suitable for stationary applications, projector mode does not need the user to divert their attention from the job at hand. Unlike the following technologies, both modalities enable user collaboration on tasks since they are not limited to a single user. HMD-AR is more user-friendly than handheld displays like tablets and monitors, nevertheless. The greatest flaw of all is that it requires the user to hold it while using it. It is not the leading technology to use for manual applications because it is not hands-free. Additionally, some operator attention must be diverted from the work (Gabriel, et al., 2022). When employing a single projector, this method's potential downside is that it may have occlusion issues. Due to the time-consuming setup and installation procedures, using a projection system would be challenging to manage and lessen the advantages of the AR maintenance support system compared to a tablet (Lorenz, et al., 2018).

7 Conclusion and future work

The solution to the research question is found in the literature review. According to the findings of the literature research, AR can increase worker safety in an HRC workplace. According to the literature analysis and interviews, visualisation is the most important category for maintaining safety. Ergonomics, awareness, and communication are the other major areas. The findings of an interview vs a literature review differ greatly. Between ideas related to AR and HRC and reality, there is a significant disparity. Studies indicate that AR is acceptable for HRC safety, although collaborative robots as a whole are not often deployed in real applications. Participants feel that AR has the potential to increase safety in several ways, but there are still certain obstacles to be solved. The challenges identified by this research include knowledge, expertise, system complexity, suitability, technology, and time. More studies that concentrate on these obstacles might aid in learning more about them and finding solutions. Similarly, when workers engage with robots using AR-enabled technology, they will be able to operate safely and foresee mishaps, increasing their faith in the robots. Although AR may be utilized to promote safety in a collaborative workplace, it does have certain limitations. According to the research study, when participants use HMD-AR, they experience various issues such as ergonomic challenges and visual concerns. When compared to other AR technologies, projective AR is more user-friendly than HMD-AR. Despite the fact that AR and HRC have numerous benefits and prospects in the future, they are not pushed in sectors owing to a lack of technologies, expertise, experience, and system complexity, according to interviewees. They believe that these obstacles may be addressed in the future, and that more companies will use AR and HRC in their work.

Because just a few organizations are interviewed in this study, and interviews in this study are complementary, a more sophisticated case study might be undertaken in the future, over a longer period of time, with more engaged companies and respondents. Rather of focusing on the benefits of adopting AR and HRC, a more in-depth case study focusing on the obstacles faced by AR and HRC in sectors may be done to learn more about the limitations of these technologies and how they might be improved. A research using augmented reality to improve HRC programming might be beneficial to businesses in learning about the most successful ways to program collaborative robots.

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Appendices

Appendix A: Article categories, step 1

Categories	Article Number	Total
Motivation for companies	1	1
Situational awareness	2,20,26,56	4
Visualisation	3,10,11,12,13,14,15,16,17,18,19,20,21,23,24,26, 28, 30, 31, 33,34,35,37,38,39,41, 42, 44, 48,	29
Workspace information	3	1
Time reduction	3	1
User experience enhancement	3,14,49	3
AR related failures and taxonomies	4	1
Importance of joint perception	5	1
Increase awareness	5, 10,12, 13, 14, 15, 16, 23, 25, 32, 34, 43, 44, 46, 48, 50, 52, 54	18
Reduce cognitive load	6, 12, 15, 16, 23, 34, 46, 47, 48, 49, 54	11
Increase satisfaction	6	1
Communication (verbal and nonverbal)	2, 7, 11,13, 16, 25, 28, 29, 30, 42, 43, 47, 56,	13
Physical effort	10, 49	2
Improve ergonomics	8, 17, 18, 23, 36, 41, 45, 52, 54, 55	10
Perception	5, 12, 18, 21	4
Mental load	16, 12, 42,	3
Training	13, 14, 21, 30, 31, 37, 38, 39, 40, 46, 54,	11
Trust	15, 16, 18, 20, 32, 36, 51, 54	8
Stress	17, 34, 46, 51	4
Reduce anxiety	18, 51, 52,	3
Collision prediction	18	1
Confidence	20	1
Performance	21, 55	2
Collision avoidance	22, 23,24,25,26,30,36,44,45,46,48,52	12
Risk visualisation	22	1
Visual cues	25, 29,36	3
Visual reference	27	1
Spatial awareness	29,42,56	3
Increase comfort	34,49,52	1
Operational availability	41	1
Spatial mapping	43	1
Visual feedback	43,53	2
Audio	43	1
Task sequence planning	43	1
Guidance	43,46,47	3
Manipulation	43	1

Speech and gestures recognition	44,45,47	3
Selection of choices(decision)	50	1
Detect fault in robot	51	1
Planned motion and trajectory	52	1
Warning	59	1
Acceptance	61	1
Error	65	1
Operator mobility	69	1

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Appendix B: Article categories, step 2

Categories	Articles	Total
Visualisation (Information, instructions, visual cues, visual reference, risk visualisation, visual feedback, operational availability, task sequence planning, manipulation, planned motion and trajectory, warnings)	3,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,29,26,27, 28, 30, 31, 33,34,35,36,37,38,39,41, 42,43, 44, 48, 52, 53,59,60,66	40
Ergonomics (Physical effort, cognitive, Stress, anxiety, perception, confidence, mental load, satisfaction, experience enhancement, comfort, selection of choices, time reduction, acceptance, errors)	3,5,6, 8,10, 12,14,15,16,17,18,20,21,23,34,36,41, 42, 45, 46, 47, 48, 49,50,51,52, 54, 55,57,61,64,65,67,68	34
Awareness (Spatial awareness, Situational awareness,	2, 5, 10,12, 13, 14, 15, 16, 20, 23, 25, 26,29,32, 34, 43, 42,44, 46, 48, 50, 52, 54,56,57,58,60,62,65	29
Collision Avoidance (Collision detection, Collision prediction, spatial mapping)	18, 22, 23,24,25,26,30,36,41,43,44,45,46,48,52,60,65,66	18
Communication (Verbal and Nonverbal,	2, 7, 11,13, 16, 25, 28, 29, 30, 42, 43, 44, 45,47, 56, 57	16

Gestures and speech, audio)		
Training (Guidance)	13, 14, 21, 30, 31, 37, 38, 39, 40, 43,46, 47,54, 60,62,69	12
Trust	15, 16, 18, 20, 32, 36, 51, 54,63,65	10

Appendix C: Article categories out of scope

Categories	Articles	Total
Motivation for companies	1	1
AR failures	4	1
AR in vehicles	15	1
Performance	21,37,55	2
AR requirements	35	1

Appendix D: Article categories, step 3

Categories	Articles	Number
Visualisation (Instructions, Information, Training)	3, 10, 11, 12, 13, 14, 16, 17, 18, 19, 20, 22, 23, 24, 25, 29, 26, 27, 28, 30, 31, 33, 34, 36, 37, 38, 39, 40, 41, 42,43, 44, 46, 47, 48, 52, 54, 53, 59, 60, 62, 66, 69	43
Awareness (Situational awareness, Spatial awareness, Collision avoidance, Trust)	2, 5, 10,12, 13, 14, 16, 18, 20, 22, 23, 24, 25, 26, 29, 30, 32, 34, 36, 41, 42, 43, 44, 46, 48, 50, 51, 52, 54, 56, 57, 58, 60, 62,63, 65, 66	37
Ergonomics (Physical, Cognitive)	3,5,6, 8,10, 12,14,16,17,18,20,23,34,36,41, 42, 45, 46, 47, 48, 49,50,51,52, 54, 55,57,61,64,65,67,68	32
Communication (Verbal, Non-verbal)	2, 7, 11,13, 16, 25, 28, 29, 30, 42, 43, 44, 45, 47, 56, 57	16

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Appendix E: Interview guide for companies without AR

	Interview Guide	
Activity	What is company's main activity?	
Employees	How many employees do you have?	
	Interview person	
Title	Role of the person	
Point of contact	How close to the robot do you work?	
	About the robot	
Numbers	How many collaborative robots do the company have?	Do you have traditional industry robots as well?
Time	For how long time have they been in use?	
Task	What does the robot do?	
Driving force	What was the biggest reason for implementing collaborative robots?	
Focus area	**Questions**	**Follow up questions**
Current situation	How do you think it works with the robot?	
		What works well?
		What works less well?
Safety background	In the initial HRC environment, how was safety maintained?	
	How safety is maintained now?	
		Are the guidelines clear, when it comes to safety?
		Where is the responsibility to ensure that the safety requirements are fulfilled?
	Have there been any accidents?	
		If yes: What happened?
		What was the cause?
		How can you prevent that from happening again?
Safety and HRC	What are the methods used to improve safety in HRC?	
	What are the reasons for implementing that specific method?	
	What are the challenges in that method?	
	What can be done in the future to get rid of the drawbacks?	
Instructions and information	How are instructions and information supplied for working near robots?	
	Is there any difficulty with that method?	
		If yes: What are they?
		What are the options for avoiding it?
	What is the attitude of workers towards that?	
	Do they feel safe and confident?	
		If Yes: What is their reason?
		If no: What is their reason?

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	How workers are trained to work near robot?	
	What is the worker's attitude toward the robot?	
		Do they trust robot?
		If Yes/No: Why? What are the reasons?
Awareness	How awareness towards HRC is promoted?	
		What are the methods used to improve awareness?
	How collision is avoided in HRC environment?	
Ergonomics	How have the robot/robots affected the ergonomics for the operators?	
	How is the work environment affected by the work with the robots?	
	Do workers satisfied and promote HRC?	
		If Yes: What is their response?
		What are physical achievements?
		What are psychological achievements?
Communication	What approaches are employed to communicate with a robot in order for it to carry out tasks?	
	What is attitude of workers towards that method?	
		Do they have proper communication?
		If Yes/No: what are the reasons for that?
		Do they trust that communication method?
		If Yes/No: what are the reasons for that?
	What are the difficulties in communication?	
Future	How do you think you will work in the future, regarding robots?	
		Have there been concerns that the robots will replace the employees?
		Do they have reason to be worried? Has it led to redundancies?
	Are there any plans to introduce additional technologies, such as artificial intelligence, VR or AR?	
		What is your opinion about implementing AR for improving safety in HRC?
		If yes: What are limitations for implementing them?
		How can it will improve instructions, ergonomics, awareness and communication in HRC environment?
	What kind of solutions do you think you will need in the future?	
	Do you think this is the future for HRC?	
	What advice do you want to give to companies that are about to get a collaborative robot?	

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Appendix F: Interview guide for companies with AR

	Interview Guide	
Activity	What is company's main activity?	
Employees	How many employees do you have?	
	Interview person	
Title	Role of the person	
Point of contact	How close to the robot do you work?	
	About the robot	
Numbers	How many collaborative robots do the company have?	Do you have traditional industry robots as well?
Time	For how long time have they been in use?	
Task	What does the robot do?	
Driving force	What was the biggest reason for implementing collaborative robots?	
Focus area	**Questions**	**Possible follow up questions**
Current situation	How do you think it works with the robot?	
		What works well?
		What works less well?
AR Technology	In your industry, what kind of augmented reality technology is used?	
	What are the reasons for implementing that specific method?	
	For how long time have they been in use?	
	Is the system prone to any ergonomic issues?	
		If yes: what are they?
		What is the cause?
		What methods are used to prevent them?
	What are limitations on implementing AR in your industry?	
Safety background	How was safety managed in the initial HRC environment?	
	How safety is maintained now?	
		Are the guidelines clear, when it comes to safety?
		Where is the responsibility to ensure that the safety requirements are fulfilled?
Accident history	Have there been any accidents?	
		If yes: What happened?
		What was the cause?
		How can you prevent that from happening again?
	Have there been any accidents after implementing AR?	
Safety by AR	How AR improves safety in HRC environment?	
	What are the challenges when implementing AR in HRC for improving safety?	
	What can be done to increase safety in the future?	
Instructions and information	How is augmented reality (AR) being utilized to provide information and instructions for using a robot to do tasks?	
	What is the attitude of workers towards that?	

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		What is the response when compared with instructions and information given using Printed sheets?
	Do they feel safe and satisfied?	
		If yes: What is their response regarding safety?
	How workers are trained to use AR?	
		What are the mandatory requirements of skills or knowledge required?
	How AR helps to train the workers in HRC?	
		Compared to previous techniques how AR improves training?
	What is the attitude of workers towards training with AR?	
		Do they feel safe and understand tasks?
		If yes: How will it enhance training worker safety and the environment?
Awareness	What approaches are employed in HRC to increase awareness through AR?	
		Do they Trust Robot?
	In an HRC environment, how is collision prevented with AR?	
Ergonomics	What impact has AR had on the ergonomics of HRC operators?	
	How is the HRC environment affected by the work with the AR?	
	Do workers in the HRC environment feel happy and want to promote AR as a way to improve safety?	
		If Yes: What is their response?
		What are physical achievements?
		What are psychological achievements?
Communication	What approaches are utilized to communicate with a robot in order for it to accomplish tasks utilizing augmented reality (AR)?	
	What are the justifications for using that particular method?	
	What is the attitude of the employees regarding this?	
		Do they have faith in that technique of communication?
	What are the challenges of using AR to communicate with robots?	
Future	In terms of AR, how do you believe you'll work in the future?	
	Have there been any indications that the AR may be used in future safety regulations?	
		If yes: What are indications for that?
	What kind of solutions do you think you will need in the future?	
	Do you think this is the future for AR?	
	What recommendations would you provide to firms considering implementing AR in HRC to improve safety?	

Appendix G: Informed consent

Informed Consent

Information about Degree project

As a part of the master's program Intelligent automation at the University of Skövde, I will carry out a degree project with the aim of investigating how augmented reality technology improves the health and safety for workers in a human robot collaboration environment.

As a part of the study, I will, among other things, interview a number of companies that work with collaborative robots, or who have plans to work with augmented reality, and your company is one of them.

The interview will take maximum of 60 minutes

Your participation in the study is completely voluntary. You can cancel your participation at any time without further justification. If you allow it, the interview will be recorded. The recording is deleted when the degree project is completed.

Thank you for participating in the study! If you have any questions. Please contact me or my supervisor.

Skövde 04.04.2022

Dinesh Chemmanthitta Gopinath

Contact information

Dinesh Chemmanthitta Gopinath

a21dinch@his.se

Supervisor

Magnus Holm

Magnus.holm@his.se

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