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Purdue PRISM Center Survey on Work, Workforce, and Factories of the Future

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ABSTRACT

As part of our five-years (2018-2023) NSF project on "Pre-Skilling Workers, Understanding Labor Force Implications and Designing Future Factory Human-Robot Workflows Using Physical Simulation Platform," our team conducted a survey. The objective: To understand the emerging applications and values of collaborative automation (CA), including cyber and AI based tools and platforms; hence, the anticipated impacts and need for the emerging technologies that we have developed, implemented, investigated, and validate during this project. Our survey, conducted during 2022-23, and its results are described in this publication. A more extensive journal article with further analyses based on this survey is under development, and will be published soon.

ACKNOWLEDGEMENTS

This survey and its analysis have been conducted as a conclusive part of our NSF Grant 1839971: Collaborative Research: Pre-Skilling Workers, Understanding Labour Force Implications and Designing Future Factory Human-Robot Workflows Using Physical Simulation Platform. The authors also acknowledge the many respondents to this survey, from universities, industries, and government research labs. Helpful ideas by our PRISM Center colleague Frederik Weber are also acknowledged.

1. Introduction

As part of the concluding phase of our NSF research project (2018 – 2023) on this topic (see Acknowledgement), we have designed and conducted a survey, with industry, services, and universities worldwide. The motivation: During the project, our team has developed, experimented with, and validated new technologies and knowledge about how workers, factories, and organizations may work in the future, in the manufacturing and production emerging environments. Education, economics, training, interactions and collaborations, physical simulation platforms, robotics and automation including cyber and AI technologies and industry case studies have been central to these investigations. Towards the conclusion of this research, we decided to ask a select group of experts, as well as potential users and implementors of such technologies about their perspectives and related reflections.

Survey objective: **What are the emerging applications and values of collaborative automation (CA)?**

What do we consider as Collaborative Automation?

(1) cobotics (collaborative robotic devices) and cyber-physical systems;
(2) collaborative digital management and decision optimization; and
(3) next generation of cyber-augmented collaboration (cyber including AI) of worker teams.

- Background is provided for each of the 14 questions, and several publications are included in the end for relevant background, if needed by each respondent.
- For each question, assume that the focus is on teams in the context of your enterprise, and that teams can include humans and collaborative automation as defined above.
- If you are not involved in CA applications, please answer based on your knowledge and understanding, from your perspective and best judgement.

2. THE SURVEY

The survey was conducted in two steps:

- A preliminary phase, to test the initial design of the survey questions and their presentation;
- The full survey, after refining the questions.

It turned out that only a few minor inaccuracies had to be clarified, based on the initial phase. In total, the survey was sent to invitees who are experts, scholars, and leaders of automation in industry, government, and universities worldwide. The number of completed surveys by the invitees is 62.

The survey was conducted as a Qualtrics survey, with the following questions and their background. Note: The references provided with the survey questionnaire to clarify the survey scope and questions appear at the end of this publication.

SURVEY QUESTIONNAIRE

Respondent characteristics:

Industry/Service classification (e.g., automotive; Research; Government; etc.):

_____

CA application in your enterprise (mark 0=none; 1, 2, and/or 3 for the CA types as defined above):
Operational ____; Planned for near future ____; Being considered ____; NA ____
Other response:

Respondent's role (e.g., VP R&D/ manufacturing/ IT/other, CEO, Consultant, Supervisor, Researcher)

_____

14 Survey questions

Background for Questions 1-10

Collaboration: Parties, including CA, share information, resources, and responsibilities to jointly plan, implement, and assess the set of activities required to achieve a common goal.

Collaborative robotic devices: Collaborative robotic devices, or cyber-physical systems, are independent/robotic devices that can support or work in the same environment as humans. Collaborative Robots (Cobots) are one example. Cobots are robots that are designed to support humans in their tasks by handling items, holding the workpiece, or working in parallel on the same workpiece or task as a collaborating human worker.

Lean (manufacturing/service): Lean aims to reduce production time by minimizing the time that is not considered value-added time; and by minimizing material waste.

Augmented reality (AR): AR uses cameras and computational systems to give workers more and faster feedback, guidelines (e.g., by AR glasses) on the surrounding workplace and work. Information can be signals, text, video, and explanations for the human senses and brain.

Automation: Operating or acting, or self-regulating, independently, without human intervention, and the science and technology that enable it.

Collaborative automation (CA): The science and technology of designing, integrating, building, and applying automation systems, devices, and technologies that collaborate effectively. CA accomplishes this effectiveness by AI and cyber techniques.

Cyber: A combination of computers, communication, information systems, artificial intelligence (including machine learning), virtual reality, and the Internet.

Artificial intelligence (AI): The ability of a machine system to perceive anticipated or unanticipated new conditions, decide what actions must be performed under these conditions, and plan the actions accordingly.

Decision support system: A decision support system uses statistical and computational apps to advise the decision-maker, based on the current state and on learning from past data, which action has the best potential/output now and in the future.

Internet of Things (IoT): The Internet connectivity of items via WIFI in order to share information. For example, smart devices and robots, pallets on conveyors and shelves, etc.

Internet of Services (IoS): The Internet connectivity of services via WIFI in order to share computerized and AI services. For example, smart active protocols, decision-support and planning algorithms, etc.

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1) Is your company/lab exploring or using collaborative robotic devices for the following tasks (Select/circle one or more answers.)

a. Lifting
b. Sorting
c. Material Handling
d. Packing
e. Storage
f. Other (please list)

2) What are tasks where human workers require the assistance of a collaborative robotic device? (Mark each from 1=Strongly agree to 5=strongly disagree.)

a. Lifting ___
b. Sorting ___
c. Material Handling ___
d. Packing ___
e. Storage ___
f. Other:

3) **Which collaborative approaches would support quality inspections**? (Mark each from 1=Strongly agree to 5=strongly disagree.)
a. Finding faults (full automation) ___
b. Finding, identifying, and locating faults (full automation) ___
c. Highlight common problems ___
d. Taking measurements & displaying with the accepted range ___
e. Other:

4) In which production function do you see a large potential for collaborative decision support? (Mark each from 1=Strongly agree to 5=strongly disagree.)

a. Assembly ___
b. Inner factory transport ___
c. Between factories transport ___
d. Packaging ___
e. Quality control ___
e. Other:

5) What are the challenges that hinder collaborative automation in your company? (Mark each from 1=Strongly agree to 5=strongly disagree.)

a. Cost ___
b. Time and effort of training ___
c. Missing know-how ___
d. Missing solution ___
e. Waiting for technology to mature ___
f. Other:

6) What factors are hindering the application of AR systems? (Mark for each from 1=Strongly agree to 5=strongly disagree.)

a. Size and weight for the human worker ___
b. Cost ___
c. Efficiency problems ___
d. Worker learning time ___
e. Other:

7) **Compare the benefits of an AR system vs. a visual display screen, and rank which is better.**
(AR=AR performs better, N=Neutral, CD=Computer/cellphone display performs better.)

a. Price ___
b. Intuitive reading/ orientation of position ___
c. Concise information ___
d. Integration into workflow ___
e. Integration into workplace ___
f. Other answers:

8) What significance is placed during CA supplier selection on the following six considerations? (Rank all six from 1=highest significance, to 6=lowest.)

a. Asked price ___
b. Trust/knowledge of the reliability of the supplier ___
c. Trust/Knowledge in quality ___
d. Estimated delivery time ___
e. Training time and effort ___
f. Other:

9) What decision-making tools are used for supply chain/project management? (Circle/select one or more.)

a. Shipping status tracking tools
b. Warehouse management tools
c. Lean inventory tools
d. Collaborative portals (communication &/document sharing)
e. Supply chain management tools
f. Other:

10) What IoT devices/networks does your company use? (Circle/select one or more.)

a. Sensors
b. Human-held devices
c. Remote monitors
d. digital twins
e. Other:

11. Background: Communicating is needed for current decisions; communicating about the future can drive performance outcomes now and in the future; leaders should consider increasing the frequency and sharing of their employee updates, while balancing more knowledge with information overloads.

11. How do you design and optimize communication and collaboration protocols, and IoS in your company and workplace? (Select/circle one or more answers.)

- Meetings apply standard remote and local protocols of video, visual, and other communications
- Meetings apply some standard and some of our company's proprietary protocols and IoS
- Teams of humans and CA apply only standard protocols and IoS
- Teams of humans and CA apply some standard and some of our company's proprietary protocols and IoS
- Other answers:

12. *Background: Employees are eager to see organizations put a greater emphasis on flexibility, competitive compensation, and their well-being. They're concerned that future work, increasingly employing CA, will negatively affect the workers' needs.*

12. **What are your views on the value and flexibility of CA to (a) the well-being and compensation of your future workers? (b) the competitiveness of your enterprise?** (Open-ended response)
Answer:

13. Background: Collaboration tools, and training for those tools, rate highly for employees, as does reimbursement for remote-work office setups. Micro-connectivity policies, meanwhile—from small team events to a listening and response strategy—were top policies for more than a quarter of all respondents in previous surveys.

13. **How can you improve productivity through collaboration, connectivity training, and technology-based application in your company?** (Select/circle one or more answers.)

- Additional mandatory networking events
- By increasing multi-disciplinary task forces within the company
- Mandatory IT training on software for collaborative interaction with CA
- Other answers:

14. Background: Companies will need to choose from the following five main types of action as they build and prepare their future workforce with CA: retraining, redeployment, hiring, contracting, and releasing.

14. **How can companies and employees adapt to the everchanging requirement of skill and knowledge?** (Select/circle one or more answers)

- Periodical employee assessment and retraining
- Promote collaboration across supply networks
- Enable faster company upscaling/downscaling
- Other answers:

Useful background publications:

Insert here

3. SURVEY RESULTS

- We received 62 complete survey responses from participants in 25 different **institutions**:

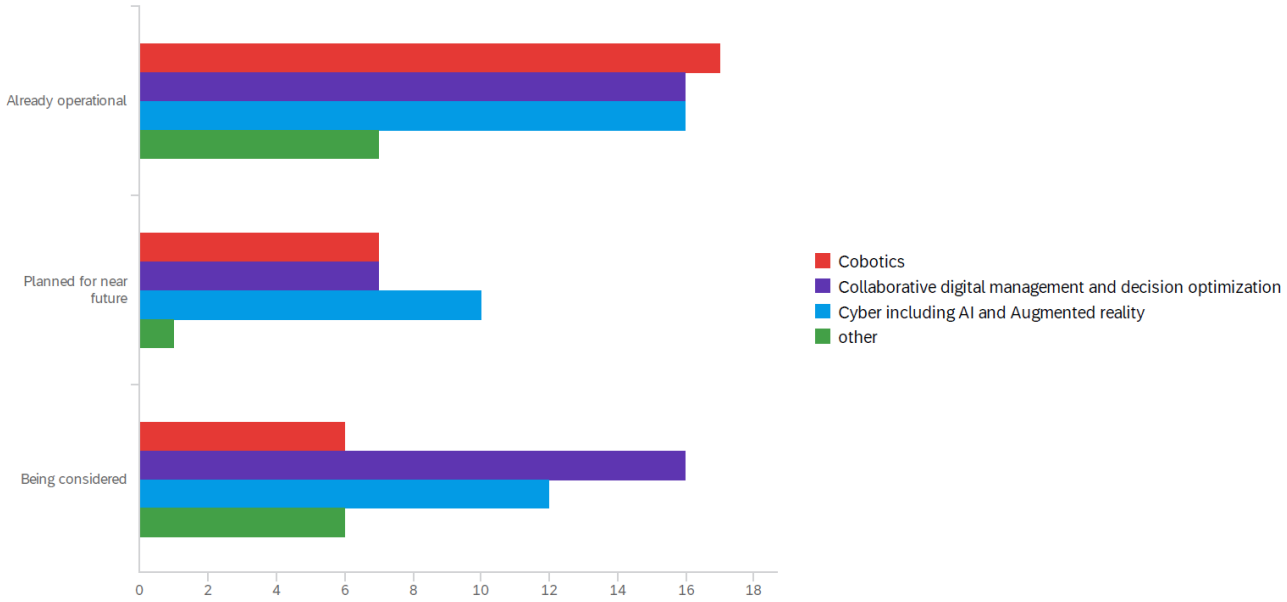
No.	Institutions of Respondents
1	3M
2	Agricultural Research Institute
3	Amazon
4	American Airlines
5	Ben-Gurion University
6	Polytechnic School of the University of São Paulo, Brazil
7	European institutions
8	Hitachi Ltd.
9	HSLU
10	Italian Inst. of Technology
11	Korea Railroad Research Institute
12	Nakanishi Research & Consulting
13	Purdue University
14	Rutgers
15	Sr. Product Manager, Precise Collaborative Robotics Group, Brooks Automation
16	Technion I.I.T
17	The Romanian Academy
18	The University of Alabama in Huntsville
19	Theme Work Analytics Private Limited
20	Tunghai University
21	Universidade de São Paulo, Brazil
22	Universidade Tecnológica Federal do Paraná UTFPR Curitiba, Brazil
23	University of Campinas
24	University of Sao Paulo
25	Virginia Tech

- The 62 respondents of this survey reported to be within the following **fields**:

No	Fields of Respondents
1	Academic
2	Agriculture
3	AI in General
4	Airline Industry/Travel & Hospitality
5	Automotive
6	Business services (consulting)
7	Communication
8	Consulting
9	Consumer Packaged Goods
10	Design optimization
11	Education
12	Educational Service
13	Electric, ICT, social infrastructure

No	Fields of Respondents
14	Government
15	Higher education
16	Industrial and digital solutions
17	Information Technology
18	Management consulting
19	Manufacturing
20	Railway Technology
21	Research
22	Robots
23	Science
24	Technology
25	Transportation Consulting
26	University

- When asked regarding the **collaborative automation application** in their respective enterprises, the respondents reported as follows:

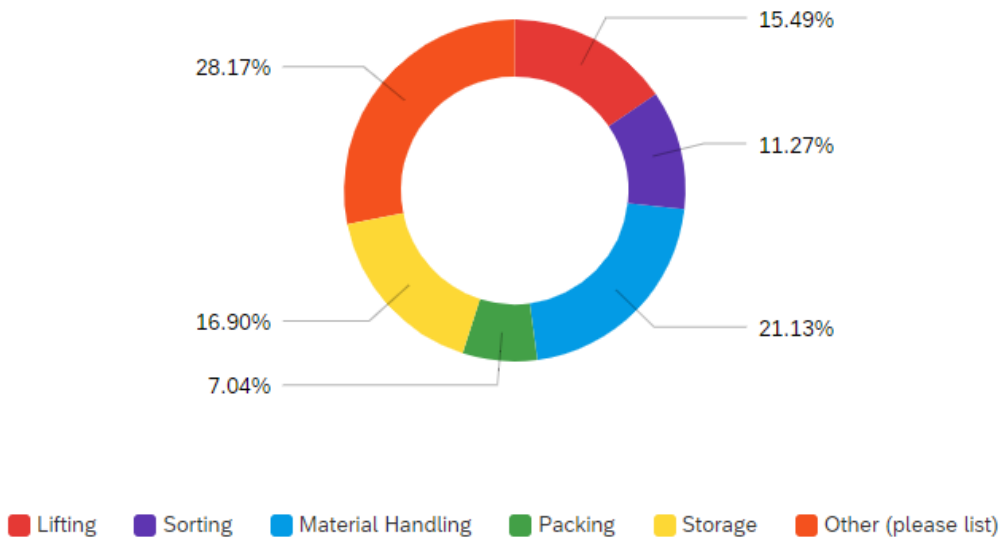


The respondents of this survey have indicated the following **role** in their corresponding fields:

No.	Fields of Respondents
1	CEO/Consultant
2	Chief Scientist
3	Consultant
4	Dean
5	Founder & CEO
6	General Manager
7	IT executive manager
8	Manager
9	Marketing
10	Open innovation
11	Principal Researcher
12	CEO/Consultant

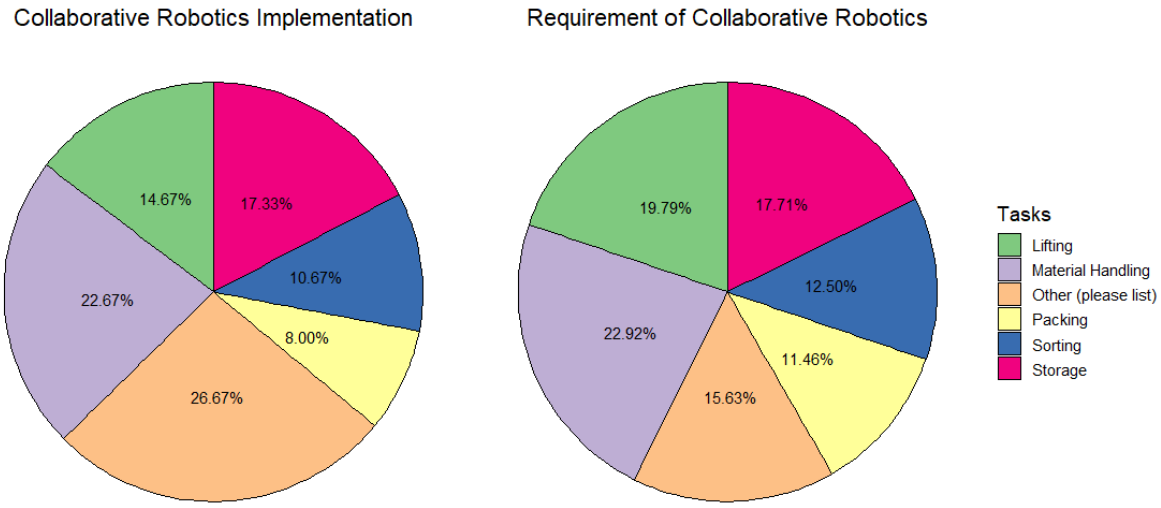
No.	Fields of Respondents
14	Professor
15	R&D engineer
16	Research Assistant
17	Research Director
18	Research Supervisor
19	Researcher
20	Researcher, Assistant Professor
21	Senior Researcher
22	Teaching-focused professor
23	Vice President
24	VP Planning & Distribution
25	VP R&D

- In the first question, we asked **whether their institution explores or uses collaborative robotic devices for several production system tasks** (lifting, sorting, material handling, packing, storage, and other). The responses are as follows:



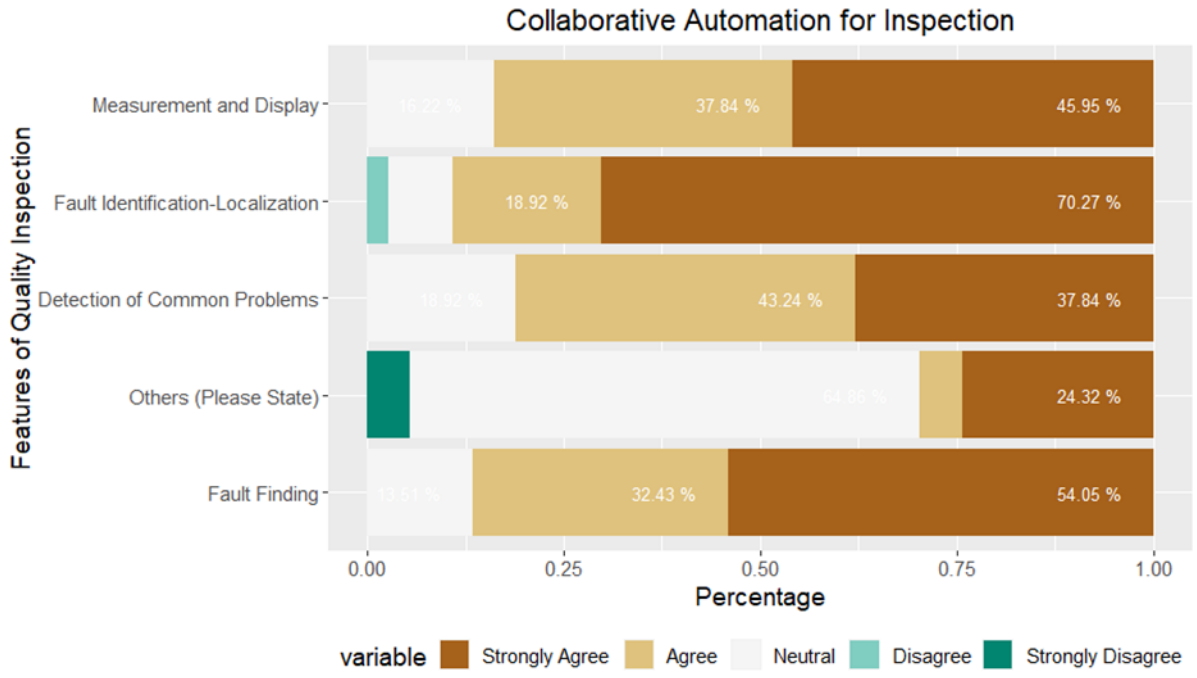
Other applications which use collaborative robotic devices include assembly, future research and development, material removal, order taking, spraying plants, transportation of items, welding, sealing, and fixturing.

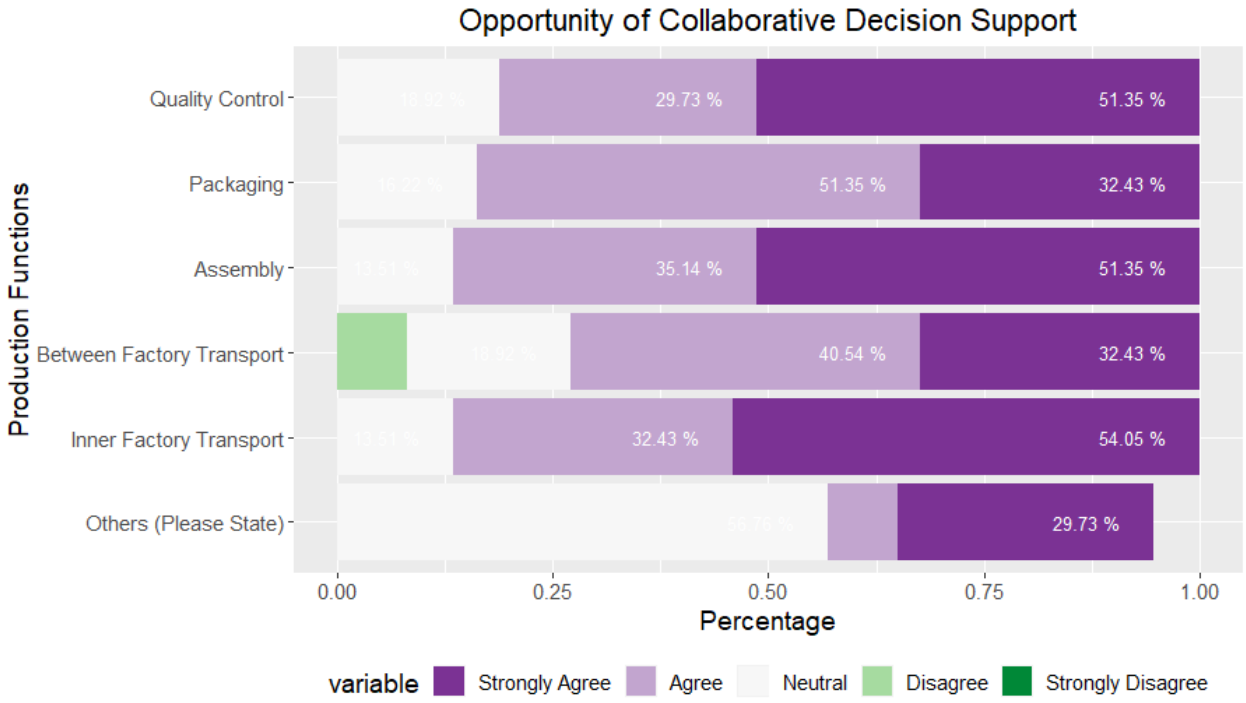
- In the second question, we inquire what are **the tasks where human workers require the assistance of a collaborative robotic device.** The responses are as follows:



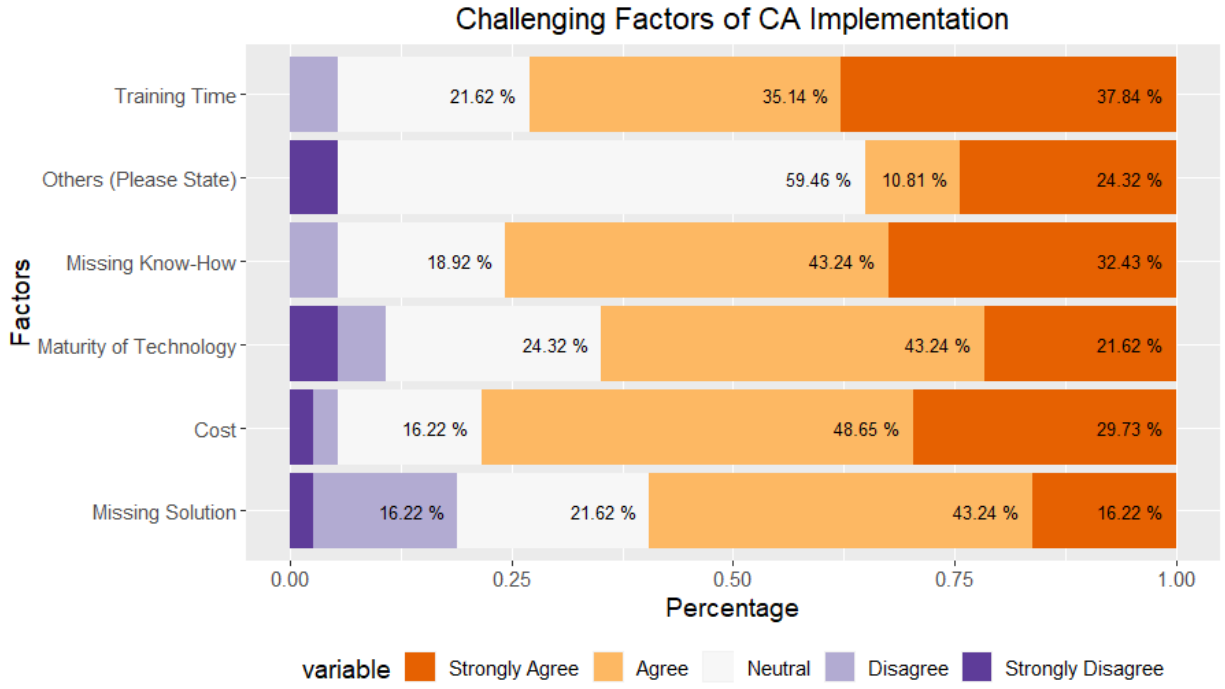
Other tasks in which human workers require the assistance of a collaborative robotic device include assembly, installation, cleaning, material removal, retrieving and transportation, spraying plants.

- In the third question, we asked **which collaborative approaches would support quality inspections**. Answers are marked between strongly agree and strongly disagree, and the result is presented in the graph below. In the fourth question, we asked **which production function has a large potential for collaborative decision support**. Answers are marked between strongly agree and strongly disagree, and the results are as follows:

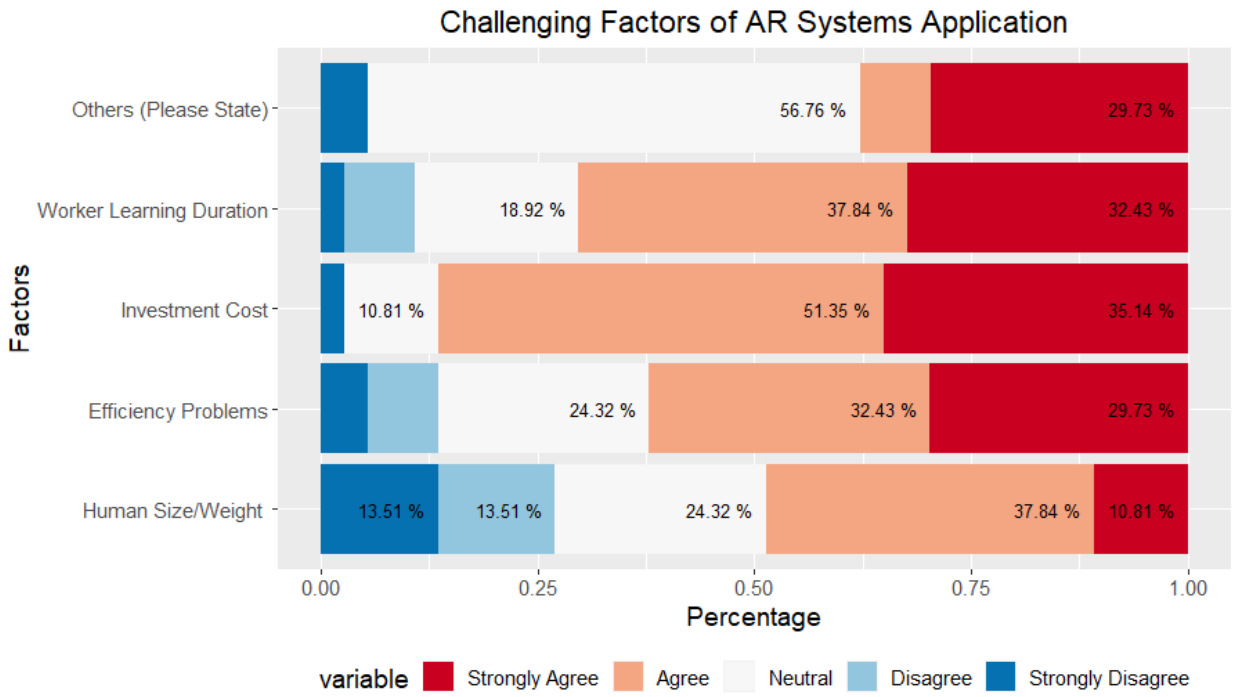




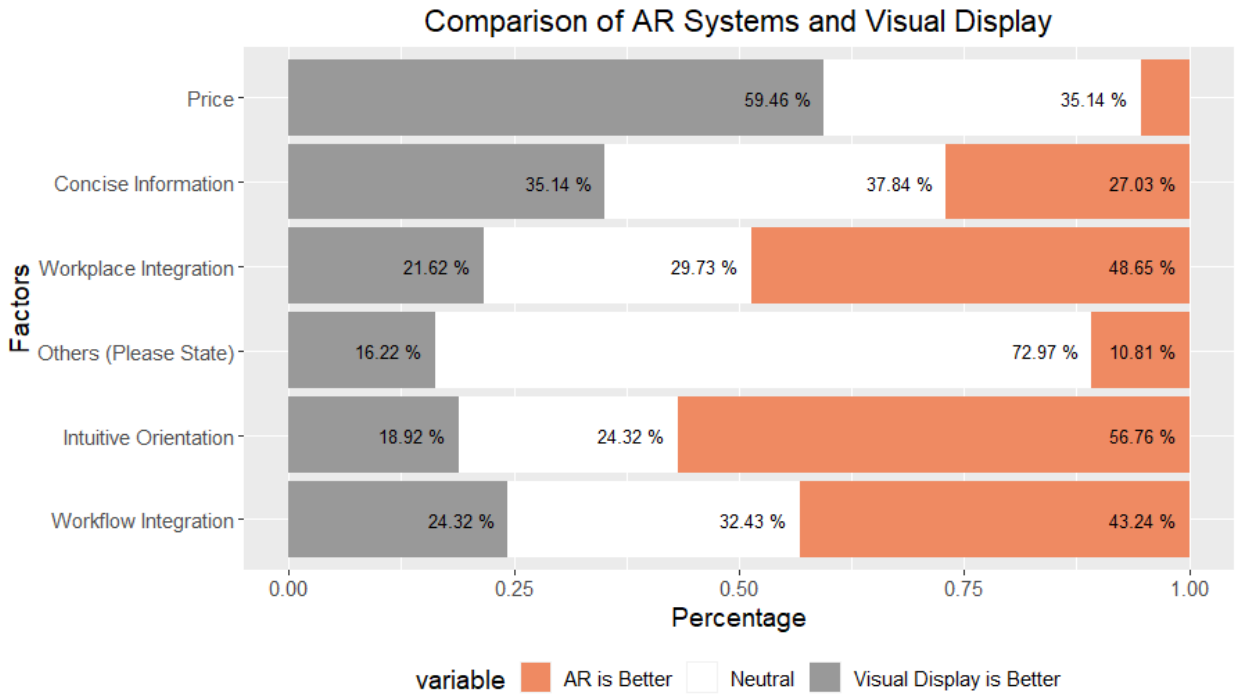
- In the fifth question, we asked about **challenges that hinder collaborative automation**. Answers are marked between strongly agree and strongly disagree, and the results are as follows:



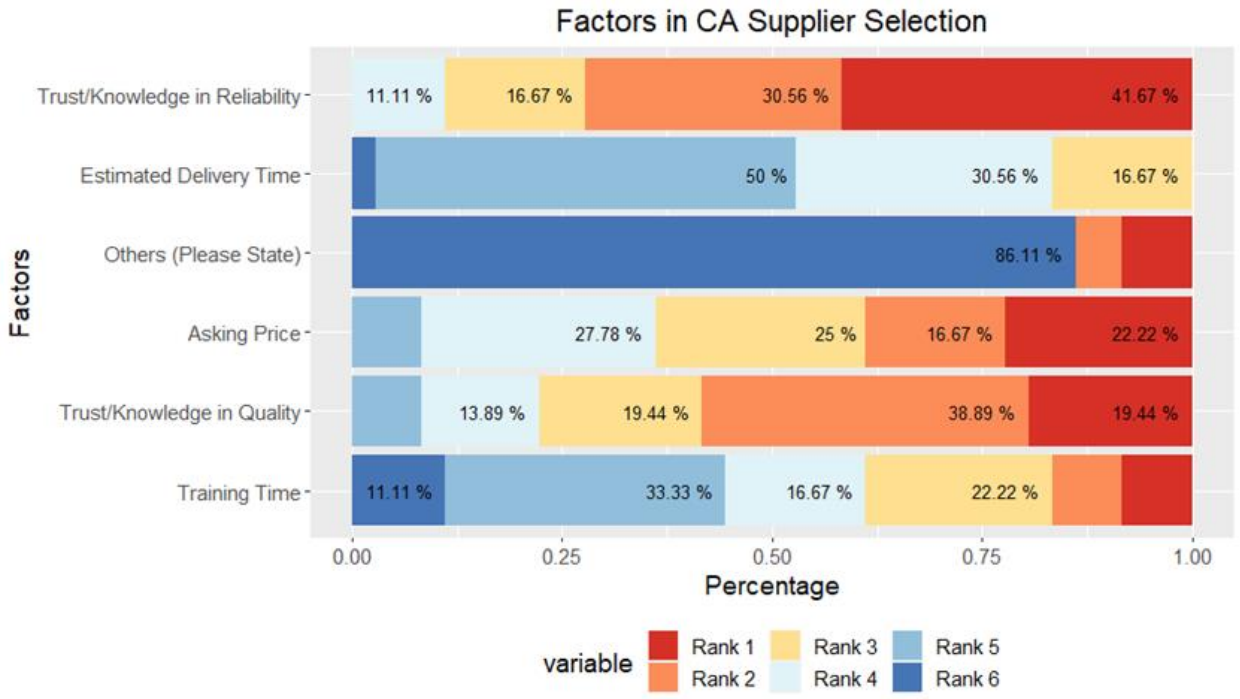
- In the sixth question, we asked about **challenges that hinder AR systems application**. Answers are marked between strongly agree and strongly disagree, and the results are as follows:



- In the seventh question, we asked our respondents to **compare the benefits of an AR system vs. a visual display screen, and rank which is better**. The results are as follows:



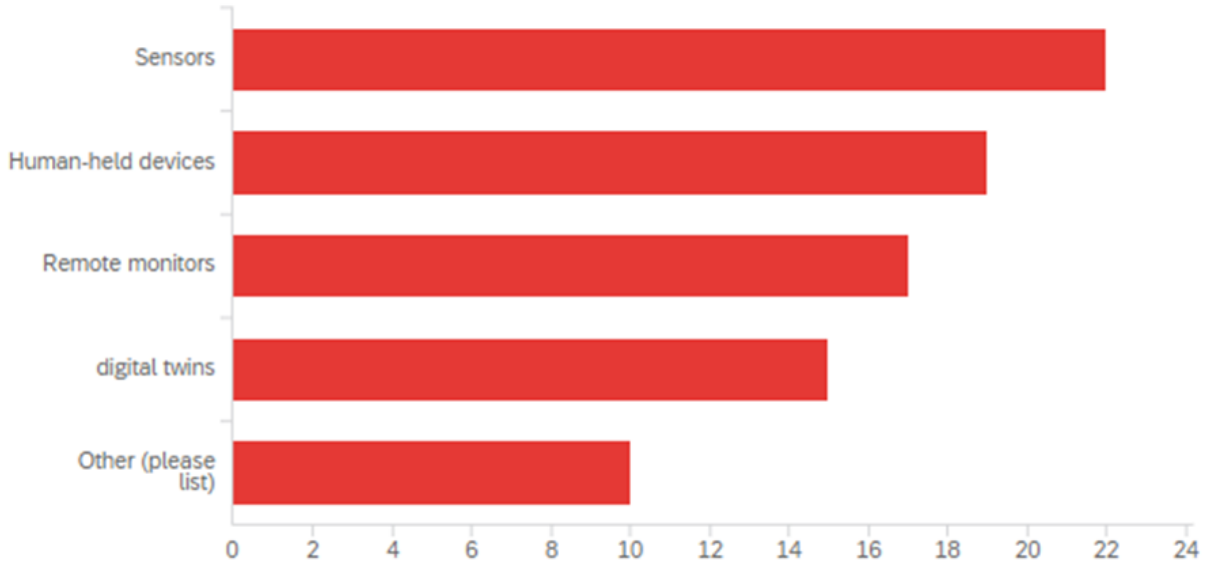
- In the eighth question, we asked respondents to **rank several considerations' significance during Collaborative Automation supplier selection**. The results are as follows:



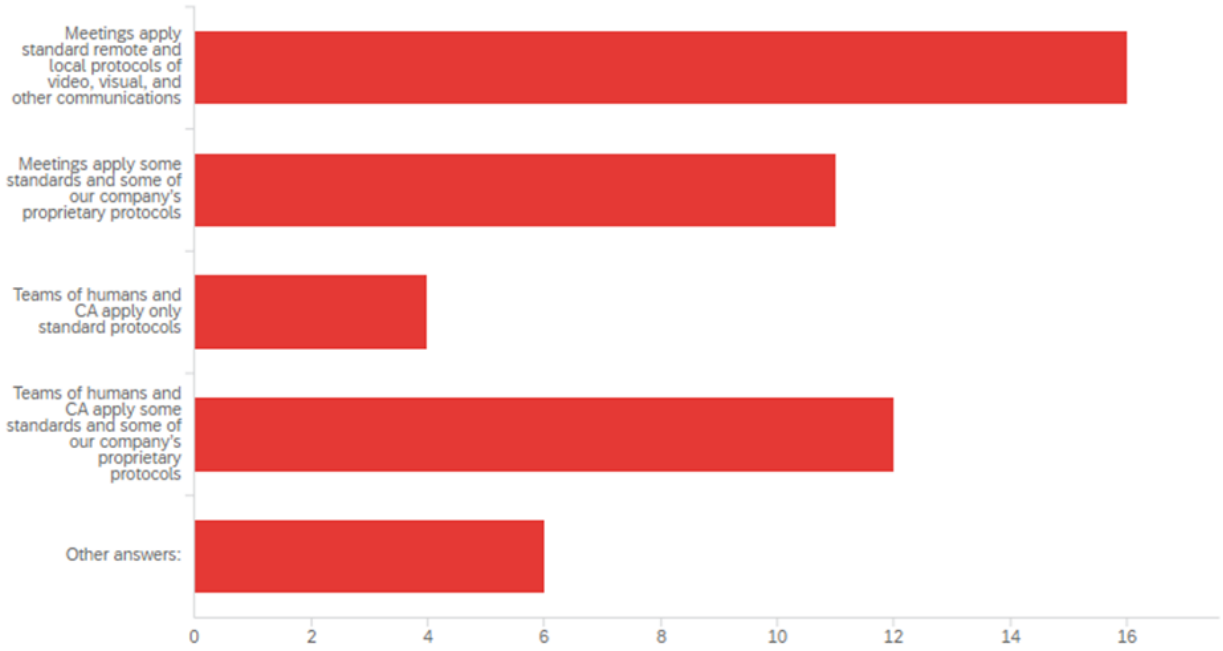
- In the ninth question, we asked respondents to **select the decision-making tools used for supply chain/project management in their institutions**. The results are follows:

#	Field		Choice Count
1	Shipping status tracking tools	17.89%	17
2	Warehouse management tools	20.00%	19
3	Lean inventory tools	13.68%	13
4	Collaborative portals (communication &/document sharing)	18.95%	18
5	Supply chain management tools	22.11%	21
6	Other (please list)	7.37%	7

- In the tenth question, we asked respondents which **IoT devices/networks used in their institutions**. The results are as follows:



- In the eleventh question, we asked respondents to identify **ways to design and optimize communication and collaboration protocols in their institutions**. The results are as follows:



- In the twelfth question, we asked respondents to explain their **views on the value and flexibility of CA to (a) the well-being and compensation of your future workers? (b) the competitiveness of your enterprise**. The results are compiled as follows:

No.	Response
1	(1) Human society is aging. We need CA to increase the productivity, maintain the quality, and reduce the risk of human work. (2) Taiwan government is supporting enterprises to apply and develop various kinds of CA technologies to keep their competitiveness.
2	(a) CA can augment human workers' productivity by supporting their work and handling tasks that are routine and/or time-consuming. It can free up human workers from repetitive and tedious tasks and help them focus on more creative tasks. Consequently, it will lead to improved well-being and compensation for the human workers as long as they get familiar with the CA environment. (b) For the same reason, CA provides a competitive edge to the company.
3	(a) concerns about safety of employees, may need higher pay for added skills related to CA, (b) it will increase the competitiveness of the enterprise
4	(a) no harm on the well-being and compensation (b) increase competitiveness
5	(a) Workers will be able to set aside repetitive tasks and concentrate on new developments or improvements to previously planned systems. (b) It can help the research laboratory through the increase in faster results and in the dissemination of those results for recognition in the academic and industrial community.
6	(a)The process of introducing AI and automation in enterprises can alleviate the overall labor shortage caused by the aging population, but it also causes some job vacancies to be replaced by machines, resulting in unemployment. On the other hand, while new technological advances can create new jobs, if labour skills do not keep pace with the times, the job market will face structural unemployment, which may lead to widening wage gaps and rising income inequality. (b)Observing the driving factors of the collaborative robot market, the shared workspace saving and the disappearance of installation space restrictions are conducive to the reallocation of resources such as production site space and circulation lines, and improve the effectiveness of

No.	Response
	space utilization. Robots taking over repetitive or dangerous tasks can also allow humans to cope with temporary situations, ultimately creating corporate competitiveness.
7	a) For the well-being and compensation of future workers, I think CA can help the workers get more efficient if they have AI to assist them to collaborate, identify and mitigate risks. This ensures that they are spending less time on manual tasks which can be done by a machine, catching error earlier which can help the workers to enhance their productivity which can have a positive correlation to their compensation. b) CA is absolutely necessary for the competitiveness of the enterprise because it enables efficient delivery by streamlining the entire end to end process and reducing manual effort. This helps with providing a better-quality experience for our customers by ensuring that the products are delivered in a timely manner
8	According to a recent MIT report, the newer wave of automation in manufacturing is not so much to replace workers but rather to increase precision, safety, and product quality. Large firms continue to automate tasks that are dirty, dull, and dangerous, but preserve value-added tasks that are the more desirable parts of manufacturing workers jobs. To remain competitive, the role and knowledge of humans should constantly be aligned with the growth of new technologies.
9	Automation can and should be implemented to benefit the well-being and compensation of future workers. This has been done many, many times throughout history. It can of course be done poorly but likely with large negative consequences for the company. CA has the power to change the paradigm and raise the game so to speak. It is properly implemented considering workers and benefits with goal of increasing capabilities for the company and allowing workers to share in the success.
10	CA can enable additional human productivity; the number of jobs removed will be les than the overall number of jobs created
11	CA enables (a) ability improvement, participation in non-skilled tasks, release from severe labor load, and work transformation from unwilling to fun, (b) enhancing attraction of workplace
12	CA is the future and we need to focus and work towards raising awareness among the personnel at all levels. That said, it's implied that the competitiveness of any enterprise, especially one that is involved in the primary sector (agriculture) and research would only benefit from CA.
13	CA will be most readily accepted where worker turnover is high, e.g. dangerous, highly repetitive, boring jobs with little variety or mental challenge. Examples in agriculture, cleaning, food preparation, clinical laboratory sample processing, etc. Workers in many industries seeking better work/life balance; discussion of 32-hour work week. Can CA increase productivity of workforce to allow this?
14	I think that CA will release the workers of boring and repetitive tasks. About the competitiveness of the enterprise, I believe it will be improved using CA.
15	I work in academia - I don't see the relevancy of this question to my organization
16	If fully and successfully implemented they could be of significant benefit. But it is not clear that this can currently be done.
17	Introduction of CA will allow human workers to focus on intelligent and creative jobs. It leads to increase of compensation of workers in the mid to long run.
18	It should increase well-being and this should be one of the first benefits that are noticed. I'd say that enterprise competitiveness comes second in terms of realized benefits as it will take longer to materialize. Finally, any role that moves into more advanced skills requirements should see compensation benefits as long as the person upskills accordingly.
19	number one priority needs to be worker safety, then product quality, then cost (in this order)
20	The competitiveness of the company is the most important.

No.	Response
21	The goal is to relieve agents from tedious work in analysing documents containing massive data reports in order to identify errors/mistakes/liars and to collaboratively elaborate synthesis reports
22	The relationship should be symbiotic between the robots and humans; it is necessary to continue improving competitiveness.
23	Unable to answer: Am a professor and not in the industry
24	Understandably, the core concern for employees seems to stem from a long history of hesitancy to new technological innovations that may invalidate certain job functions. Overall, I think that employees are a top priority and technological innovation should not be leveraged in a manner that harms such a relationship. However, in pursuing such a technological transition, it is often vital to support employees in transiting to new job roles (if such a change were to happen). In this scenario, new positions (often white-collar roles) will become available given the reduction of needs for human labor in certain functions. Training and education may be offered by the company in order to best accommodate employees in making such a transition.
25	Value of CA tools and applications must be established apriori. Projects, including the pilots, can be a success in implementation only when all stake holders know for sure how it benefits them and the organization. the value analysis has to be done in a comprehensive framework that considers the money gain, impact on work hours, methods, commuting time and adverse impact on any stakeholder. Flexibility has to be an integral aspect of design of the chosen CA system. The trade-off between building flexibility vs total project cost must be weighed ahead of time and buy in from all stakeholders obtained. Competitive compensation must be a basic tenet of the organization. Compensation can be considered holistically. It can include flexibility, deferred vs current, fixed vs performance based etc. A fair system needs to be designed and perceived to be so by all workers. None of the above can be realized at the cost of market competitiveness. The firm should use analytics coupled with market sensed data to feel the pulse of the market on an ongoing basis. The firm has to gain self-assurance that the market perceives its products and services as fair value for money. As a corollary, if the CA project would result in gain for the firm but not for its customers, it has to go back to the drawing board. The gains of automation projects must be shared with employees, vendors and customers.
26	We work on a hospital application using collaborative robots to retrieve medication and medical equipment and transport to the place where it will be used, well-being is related with a proper and automated workflow and competitiveness with the time expended to complete the mission.

- In the thirteenth question, we asked respondents to state **ways to improve productivity through collaboration, connectivity training, and technology-based application**. The results are compiled as follows:

#	Field		Choice Count
1	Additional mandatory networking events	13.56%	8
2	By increasing multi-disciplinary task forces within the company	38.98%	23
3	Mandatory IT training on software for collaborative interaction with CA	38.98%	23
4	Other answers:	8.47%	5

Other responses include instruction support by AI, more intensive training on business intelligence tools, and the consideration of several trade-off: (1) more networking events and meetings will reduce actual work time, (2) increasing multi-disciplinary capabilities could reduce specialization, (3) more CA software training could also reduce proficiency with specialized software.

- In the last question, we asked respondents to state **ways for companies and employees to adapt to the everchanging requirement of skill and knowledge**. The results are compiled as follows:

#	Field	Choice Count	
1	Periodical employee assessment and retraining	36.51%	23
2	Promote collaboration across supply networks	31.75%	20
3	Enable faster company upscaling/downscaling	22.22%	14
4	Other answers:	9.52%	6

4. REFERENCES SHARED WITH THE SURVEY QUESTIONNAIRE

The following selected references were provided as background, if necessary to clarify the survey scope and questions from our research project perspective.

(1) Cobotics (collaborative robotic devices)

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