Human Robot Collaboration in Industrial Applications

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***Abstract*—Nowadays, in many modern factories, the transport of products and the assembly of parts are carried out by robots. These robots increase production efficiency and save labor and money. However, getting the robotic arms to correctly identify the required parts and transport the products to the right place is still a challenge. To solve this problem, we conducted a user-centered design iteratively. Ideally, the user can specify specific inputs and outputs (i.e., different colors correspond to different exits). And people are also part of the system supervision system so as to give full play to the advantages of humans compared to robots in terms of the subjective initiative. Our system solves real-world classification problems by combining the strengths of machines in repetitive tasks with humans. And use this as an experimental basis to create a questionnaire. We analyzed the questionnaire data and found that our system can better achieve classification through human-robot interaction.**

***Index Terms*—Human-Robot Collaboration, Color Recognition, Collaborative tasks, Industrial applications**

I. Introduction

Due to the recent customer-specific mass production trend, industrial assembly faces increasing competitive pressure. As a result, companies are challenged with economic and technological optimization. Modern production systems must be flexible to adapt to increasing product complexity while handling the growing number of variants, decreasing production lot sizes, and shorter product life cycles [1]. Maintaining high product quality while keeping costs to a minimum is essential. To overcome these production challenges [2], collaborative robots (Cobots) are finding their way into industrial applications to enable human-robot interaction (HRI) with various collaboration characteristics.

On the one hand, Cobots are flexible and enable semi-automated production systems as they can be operated without safety fences alongside human workers [2]. On the other hand, the strengths of each party can be combined, such as the human's sensory abilities and the robot's repeatability and ergonomics, resulting in an improved collaboration [3]. Nevertheless, it must be noted that the widespread use of Cobots depends on various factors. Worker acceptance, a clear and reasonable assignment of work tasks, and interaction and documentation mechanisms for shared assembly sequences are critical factors for the adoption of Cobots in the industry.

With the third industrial revolution underway, Cobots have become deeply integrated into human production and daily life. Recent advancements in computational intelligence, sensing, big data analytics, and corresponding mechanical motors and structures have rapidly transformed and revolutionized traditional industries towards robotized, integrated, digital, and intelligent industrial models [4]. However, most Cobots are still identified as tools during activities, and the relationship between them and humans is still that of master and servant, where people *use* Cobots instead of *collaborating* with them. The lack of understanding and development regarding human-robot interaction in everyday life has resulted in HRI being relatively neglected by the community, despite its application in special fields, such as autopilot for aircraft. Although

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the need for HRI applications is significant, the mature and available HRI applications are not yet widely applied [5].

Although numerous studies on HRI exist, the majority of them are still focused on Single Model Human-Robot Interactions (SHRI) rather than Multimodal Human-Robot Interactions (MHRI) [6]. Compared to MHRI, SHRI is used in a much narrower context because one person can only interact with one or one kind of robot individually, without combining those robots together, which results in a one-to-one human-robot relationship. In this case, if humans want to achieve a large Cobot system using SHRI, it would require significant human resources to control. However, in the case of MHRI, a robot-robot relationship exists as well [7]. Thus, several humans can control and manage a huge robot system because of the information transmission between the various parts of the system. This ability highlights the enormous potential of HRI in intelligent manufacturing. Therefore, in the present project, we aim to develop a robot system that enables collaboration between humans and Cobots, with an integrated control window for collaboration with staff throughout the entire system. This system will increase production efficiency, liberate productivity, and facilitate the development of intelligent manufacturing. The research context we are focusing on is the assembly industry, where human beings work closely with Cobots on a daily basis. These work practices inform our design of the Cobots in this study, with a focus on collaborating with robots to accurately and efficiently collect and position objects.

The research question for this work is how to design Cobots to work together with human workers. The paper is organized as follows: Section 2 introduces the related work and potential applications. Section 3 presents our design principles and customized algorithm for the cobots. We conducted a round of qualitative analysis and an experimental study to give feedback on our iterative design process, which we present in Sections 4 and 5. Discussion and reflection are provided in Section 6, and the paper concludes in Section 7.

II. Related Work

In recent years, research and industrial applications have demonstrated that advancements in hardware design for robotic platforms have enabled the implementation of various control modalities to improve interactions with humans and unstructured environments. Human-robot collaboration is a critical application area for integrating robots, as it has high socio-economic impacts and helps maintain the sense of purpose for those involved [8].

Some researchers also suggest that in the future of the industry, humans and robots should work together and complement each other's weaknesses. This can free humans from repetitive tasks and allow them to focus on creativity and innovation. In fact, many manufacturing systems are human-centric, with human operators interacting with the smart devices around them, and human-in-the-loop [9], [10] is the key idea that supports it. Additionally, robots can provide a level of safety and security, helping to prevent human errors [11]. In line with this trend, an increasing number of robots are being utilized in industries such as product manufacturing. Complex but linear work practices are assigned to robots to complete. To accomplish these tasks, robots are designed to comply with cognitive abilities similar to those of humans, enabling higher levels of cooperation and communication [12], which can help to achieve human-in-the-loop in the industry.

The advancement of complex work tasks has introduced new requirements and led to new types of human-robot relationships, such as Multimodal Human-Robot Interaction. In modern industry, robots are required to collaborate. However, as the number of collaborators increases, the interaction between robots and humans becomes more complex. Although multiple interactions are not new in the human-robot interaction field, finding an affordable way to support the industry, in reality, remains a challenge. Many researchers have used advanced sensors to support cobots and people. However, requiring all industries to undergo a digital transformation to meet modern manufacturing needs may not be economical. Nonetheless, these sensors can collect various types of data, such as human gestures, expressions, and language, which can be analyzed [13], [14]. However, utilizing those data to facilitate better collaboration between humans and a group of robots is a challenge [15].

To address this challenge, researchers have used swarm robots as a primary tool to facilitate collaboration among robots and between robots and people in manufacturing. Inspired by the self-organized behaviors of social animals, researchers aim to design scalable, powerful, and flexible collective behaviors that enable robots to follow manufacturing rules effectively [16]. In this sense, many robot-dependent industries can upgrade their robot systems using this technology and maximize system efficiency through overall planning and collaboration with robots. The potential for applications in logistics and inspection is enormous. Furthermore, the application of swarm robots in intelligent manufacturing compensates for the weaknesses of traditional human-robot interaction in inter-robot information interaction. It enhances the performance of human-robot interaction in terms of reliability, adaptability, robustness, and scalability [17].

On the other hand, in a Multimodal Human-Robot Interaction (MHRI) system, the basic robotics system is distributed computing [18]. MHRI systems can provide each robot or component of the system with its computing units to support specific computations. By combining this technology, an industrial system in a factory can be considered as consisting of several subsystems, each with its computation capability. They can communicate with each other and work autonomously in coordination. This is an essential topic in smart manufacturing, and it supports the application of human-robot collaboration in intelligent manufacturing and drives its development.

Thus, to better design a collaborative robotic system to support industrial assembly tasks, our research question naturally raised how to bring manufacturing workers' everyday work practices into robotics system design. In turn, how can the robotics system collaborate with the workers to complete tasks? In line with these questions, we present our methodology applied to the present work. Following that, we present how to incorporate those insights of the workers in the robot system design process.

III. System design

A. Methodology

During the ethnographic work, we observed the workers' work practices and took notes on their interactions with the materials and the assembly line. We also conducted interviews with the workers to gain insights into their experiences and perspectives on their work. We asked questions such as how they interact with the materials, what challenges they face, and what improvements they would like to see in their work environment. Based on the observations and interviews, we identified several insights that could inform the design of a collaborative robotic system. For example, we found that the workers often had to handle heavy and bulky materials, which could cause strain and fatigue over time. We also observed that the workers had to move around the assembly line frequently, which could be time-consuming and disrupt their work rhythm. Using these insights, we designed a prototype robotic system that could assist the workers in their tasks. The system included a robotic arm that could lift and move the materials, as well as a mobile robot that could follow the workers and bring the materials to them. The system was designed to be easy to operate and could be controlled by simple gestures or voice commands. We then tested the prototype with the workers and observed their interactions with the system. Based on their feedback, we made several improvements to the system, such as adjusting the height and reach of the robotic arm to suit the workers' needs better. In summary, our methodology involved using a light ethnographic approach to gain insights into the workers' work practices and using these insights to inform the design of a collaborative robotic system. By involving the workers in the design process, we were able to create a system that was tailored to their needs and could improve their work efficiency and reduce their physical strain.

B. Data collection and analysis

The work started from August 2022 to January 2023. We observed the participants in a factory that is located in Kunshan, Jiangsu. Sixteen observation sessions were conducted with a set of semi-structured interviews followed up. Each observation took 1 hour with an hour of interview. In the questions, we asked about the important elements of robots-supported industrial assembly to confirm what we have observed during the work every day. Each day after the observation and interview, three of the authors transcribed the notes and interview materials. One hundred seventy-nine pages of notes were generated. And all authors carefully read and approved the data analysis. In particular, we outline those interesting events and themes of our analysis to support the next round of observation and interview on another day. This activity ensures that the next round of observation and interview can fruitfully cover our interested themes of human-robot interaction in industrial assembly work. We conducted the data collection and analysis process until the end of the technical design.

C. Technical design

We bypass the master-slave relationship between man and machine but focus more on their cooperation. Instead, we design human-in-the-loop to support the collaboration between robots and humans, offering robots automation and giving humans autonomy. To implement our design, we translate and optimize this design into three parts: 1) image transfer, 2) color recognition, and 3) aruco code recognition.

The color and Aruco code recognition form the identification part of the system. The purpose is to enable the system to identify and classify the target objects. The robot can share the identified data with the following robots without recognition functions. This enables the chain of the robots can inexpensively recognize the objects. For example, once the first robotic arm recognizes the object, it passes the captured information, including pictures, and related videos, to the partner robot. In that sense, humans can easily cooperate with any robots in the assembly chain. This also can help users better understand the current working situation of each part of the system. As a benefit, users can adjust the parameters in the system via the GUI to manage the whole system.

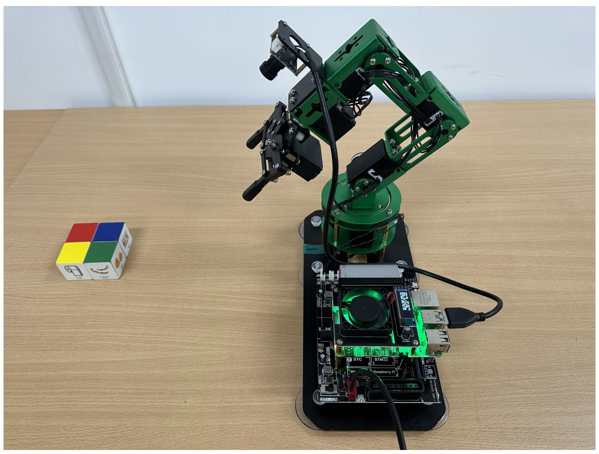
To implement the Cobots, we divided the system into seven parts:

- Pixel-based color recognition
- Calibration and identification of Aruco codes
- UDP-based real-time video transmission
- Database
- Mechanical operation
- Graphical User Interface
- Security

In line with the above seven parts, particularly for image transfer, we designed a system based on the UDP and built it in the Python environment. With this, our image transfer is divided into two parts, sender and receiver. Then the receiver (GUI) will receive a screen from the sender (robots with cameras) so that users can view the footage captured by the robot in real-time. This helps users better understand how the system is performing, which is part of the "human-in-the-loop" in the system.

To achieve color recognition, we use the HSV color module to identify colors, which classifies the color by their Hue, Saturation, and Value. However, color recognition in this way is easily affected by ambient light and background color. In order to resolve that issue, we use a Proofreading procedure to determine several target colors (e.g., blue, red, green, and yellow) and set their lower threshold boundary and upper threshold boundary defining the colors in each environment. As shown in Fig. 1, invoking to program, users need to adjust the HSV threshold for each color according to the color plot and the binary plot. And this feature brings the color recognition module to a usable range.

(a) color Recognition Interface



(b) Corresponding acttions

Fig. 1. The Reuslt of color Recognition and Corresponding acttions

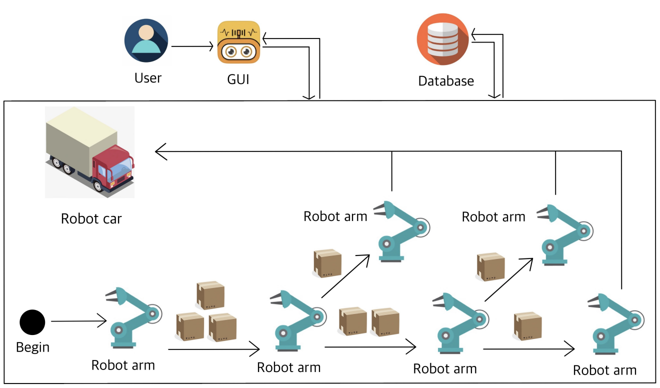


Fig. 2. System Overviewn

Figure 2 below is a scope of the system overview. Our idea is that we use the first robot with a deep analysis camera to recognize and record the box information, including colors, shapes, and sizes. Once the information on the boxes is recorded, then the robot can upload that information to the cloud. We set up a cloud to collect and store information. Each box will be stored with a specific tag. The tag is then pasted to the box by the robot arm. In the assembly industry, the rest robots in the chain can only read those QR codes on the box with a regular camera. In that sense, the chain will be inexpensive to deploy in real cases.

Emote control cars, all equipped with a camera on their heads. We programmed the robots to recognize colors and identify objects' information and deployed our application onto them. By linking the robots' WiFi and logging into the APP that controls them, the computer can gain control and give instructions to the robots. Additionally, users can see real-time images in the software. To use the robots, people need to connect to the robots' WiFi, which is password-protected, to ensure that only authorized personnel can use the robots, making them safe.

D. Algorithm of Robot Arm

In accordance with the technical design mentioned above, some algorithms are explained in detail in this section. The robot arm adjusts the angle of the end joint to pick up the blocks. We present two angles in advance to initialize the clamping and non-clamping states. The control algorithm for this part is relatively simple, as it has gears to assist in the linkage.

Algorithm 1 Robot arm clamp blocks

Require: Clamp parameter $arm\_clamp\_block(enable)$
Ensure: The state of robot arm clamp $time\_sleep$

if $enable == 0$ **then**
  $Arm\_serial\_servo\_write \leftarrow (6, 60, 400)$
else
  $enable \neq 0$
  $Arm\_serial\_servo\_write \leftarrow (6, 135, 400)$
end if

In addition to this, the overall control of the robot arm requires five motions to operate in conjunction. More complex than the algorithm for clamps, these motives are controlled simultaneously by well-defined functions. We set up similar algorithms for the individual motives in the commissioning and achieve overall control by adjusting the parameters.

Algorithm 2 Robot arm overall control

Require: Motion parameter
Ensure: The state of robot arm clamp $time\_sleep$

for $i = 1 \rightarrow 5$ **do**
  id = i + 1
  if id == 5 **then**
    time.sleep(.1)
    $Arm\_serial\_servo \leftarrow (id, p[i], int(s\_time{*}1.2))$
  else
    $Arm\_serial\_servo \leftarrow (id, p[i], s\_time)$
  end if
end for
time.sleep gets (s_time/1000)

In this scenario, the robotic arm clips the objects based on first determining the color of the objects and then sorting them for placement. On top of the clip, a camera is dedicated to recognizing the color. Based on the results obtained from the HSV file extraction, the algorithm presets four recognition results of yellow, green, blue, and red, and corresponds to the position where they should be classified. The algorithm for color recognition is shown below.

Algorithm 3 color classification of blocks

Require: Image parameter img
Ensure: Classification $color\_name$ and action g_state_arm

```
Get the color of the image and save in HSV text
if HSV in range [26,34] /[35,78] /[100,124] /[0,10] and [156,180] then
    color_name is yellow /green /blue /red
end if
ctrl_arm_move in index
arm_clamp_block start from 0
if index == 1 /2 /3 /4  then
    print(yellow /green /blue /red)
    turn on Arm_Buzzer
    number_action according to index
    put down block
end if
return g_state_arm
```

IV. Experiment

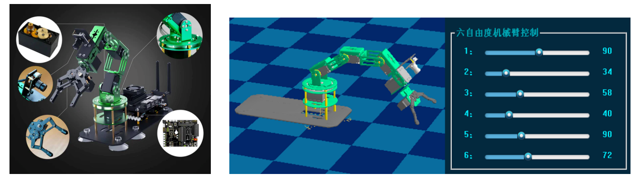
The user study aims to fill the aforementioned gaps in the literature by investigating the effects of various human-robot interactions on users' performance and perceived workload in our designed tasks. We approached the study as a way to gain insight and understanding, rather than purely testing specific hypotheses because previous research on human-robot interaction had inconsistent findings in man-machine collaboration. Therefore, there was not enough information to form reliable hypotheses.

A. Participants Arrangement

Our experiments recruited 15 pairs of participants (15 females) from a local university, aged between 20 to 27 (M= 22.5). They conducted two sets of experiments and filled out questionnaires for the corresponding experiments after each experiment was completed. Most of the participants were studying Human-Computer Interaction. All participants had normal or corrected to normal health status. None of the experimenters had ever conducted similar experiments before, and they accepted the necessary pre-training exercise to guarantee that they can use the devices to finish the experiment individually.

B. Devices Used

For this study, we mainly use the Yahboom DOFBOT, whose component details are shown in Figure 3(a). It contains 6 HQ servos, an HD camera, and a multi-function expansion board. They can be controlled by mobile phone apps, PS2 handle controllers or the upper machine software on the PC. Due to the reason for controlling the experimental variables and the efficiency and fairness of the experiment, both groups used the upper machine software to control the robots, which is shown in Figure 3(b).

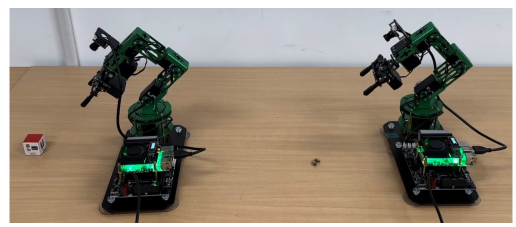


(a) Yahboom Dofbot (b) The Upper Machine software

Fig. 3. Yahboom DOFBOT and its upper machine software

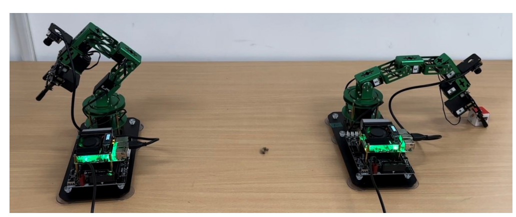
C. Task and Procedure

In these experiments, we required participants to move the colored boxes (each measuring 3cm $\times$ 3cm $\times$ 3cm and marked as red, blue, green and yellow) from an initial place to the end through two different Dofbots. The aim of these tasks is to simulate the situation in which workers control an industrial arm to sort different items and compare its performance with the performance after adding a color recognition function.



(a) The First Works

(b) Handover Work



(c) The Second Works

Fig. 4. The Reuslt of color Recognition and Corresponding acttions

Both the normal and color recognition (operate with color recognition help) groups use the upper-machine software in the PC to remotely control the two Dofbots. In the normal group, participants need to control the first arm to pick one box to the corresponding median place, and then use the second arm the pick the box up again and move to the final aim place, the whole process is according to the displacement shown in the PC from the HD camera and the gesture of Dofbots in reality so that the difficulty of this experiment is humans need to judge the posture of the robot arm by themselves. In the automatic color recognition group, participants only need the use the upper machine software to choose one color they want, the whole system would work automatically, and the two arms will move the corresponding box to the designated location.

In the pre-training state, participants are allowed to use Dofbots to move the boxes freely and learn some basic functions of the upper machine software, they can command the control methods of Dofbots in this state. In the formal experiment state, different participants need to achieve different tasks. Members of the manual (normal) group need to attain (1) use the first Dofbot to catch the needed box in the initial place; (2) Rotate the angle of DofBot's joints to put the box to the median place; (3) control the second Dofbot to repeat the above task to put the box to the terminal. Members of the automatic (color recognition) group only need to attain (4) control the first robotic arm performs color recognition on objects in its field of view to judge whether it is the needed box; if it is, the arm will atomically move it to the relay station place, and then the second will wait to obtain the box immediately to put it in the right place. After finishing the experiments, participants must answer both NASA-TLX and SUS questionnaires to record their feeling and experience. analyzing the results of the experimental data.

D. Hypotheses

To answer our research questions, we present three hypotheses and focus on investigating how the robotic collaboration system may work in its possible future application scenarios, with a specific emphasis on Dofbot's work operability (convenience) and work performance (color recognition error rate, capture success, and elapsed time).

- H_1: With the help of the automatic system, the time and operation in the color recognition needed to finish the tasks would be less than the normal group.
- H_2: As the algorithm and the hardware used in the experiment may be relatively simple, the probability of errors in the experimental group may be higher so that users in the artificial group may feel more confident than users in the automatic group.
- H_3: Compared with the artificial group, the robot of the automatic group is easier to understand and finish these tasks.
- H_4: With the help of the automatic system, the overall performance (a combination of the evaluations of participants' mental, physical, and temporal demands) for the normal group may be higher than color recognition.

V. Result and Analysis

To evaluate the performance and workload of human-robot interaction, we used the NASA-TLX and SUS questionnaires. The SUS questionnaires use 5-point scales (1-5), while the NASA-TLX questionnaires use 11-point scales (1-11). NASA-TLX measures six elements of users' workload (mental demand, physical demand, temporal demand, overall performance, effort, and frustration level). SUS measures six elements of users' performance and preference (system functions, design issues, ease of use, user confidence, affordance, and usefulness).

For the related data collected from experimental participants, we analyze them by the Shapiro-Wilk test, which shows that the data's $\boldsymbol{p} \geq 0.05$ and the absolute value of ***kurtosis*** and ***skewness*** is less than *10* and *3*, which proves our data were normally distributed. At the same time, the Quantile-Quantile Plot also confirms this result. These two things guarantee the credibility of our data and help us to continue further research. Furthermore, our group performed a confidence analysis for two questionnaires by calculating ***Cronbach's*** α constant value. The corresponding ***Cronbach's*** α values of SUS and NASA-TLX are *0.975* and *0.953*, and the normalization ***Cronbach's*** α values are *0.976* and *0.951*. These data certify the credibility of these two questionnaires.

A. Objective Results

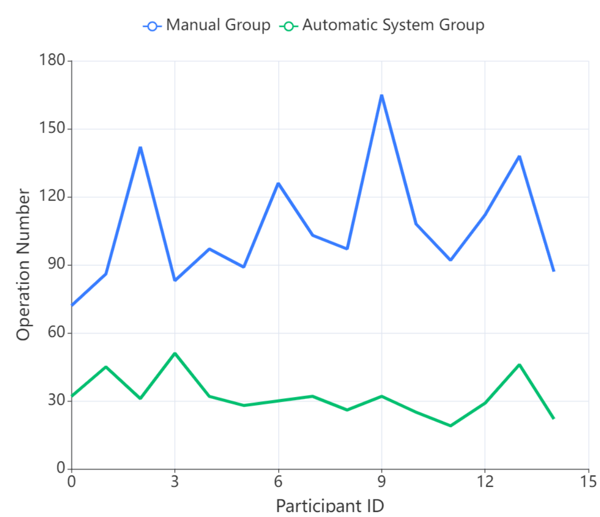


Fig. 5. Operation Times of Manual Group

All the data about the time each participant spent in each task and their experiment details are recorded by our videos and the data results are shown in Fig. 5. The number of operation times is also counted during the experiment as objective criteria to help us to evaluate their performance. It is clear that all participants' operation numbers fluctuate between *72* and *165*. However, the mean number of operations the automatic system takes in normal situations is just *32* in each experiment, which is observably less than the manual group. Results of paired samples t-tests on the mean number of operations also show a significant difference between the two groups ($\boldsymbol{t}$ = *10.698*, $\boldsymbol{p} \leq 0.001$). These data support H_1. Due to the whole system being still in its infancy, we infer that the hardware and software of the system cause some technical issues increasing the error rate (H_2). According to the statistics results, we confirmed the automatic system exactly exists a certain amount of instability which would cause errors. However, we found the error rate of the manual group is even higher, which opposes H_2. One reason is participants in the manual group need to pay attention to too many factors to control the arm. The other is facing delay and repetitive work, their attention and judgment may decrease causing more errors.

B. Subjective Result

By analyzing the "easy to use" item in the SUS questionnaire, we found that there was no significant difference in the mean values of the two prototype operating modes is similar. However, relatively the color recognition mode has a higher maximum, and higher 25% and 75% quantile, which supports that the comprehensive evaluation of the color recognition group performs better (both two running styles' modes got four as their median scores). This result shows that the color recognition group is convenient to use, which conforms to the H_3.

The cross-analysis of the SUS and NASA-TLX questionnaires shows that the high marks for convenience (4-5 scores) overlap significantly with the high marks for mental, physical, and temporal demand (7-11 scores). This data supports the reliability of the results and suggests that participants found the automatic group more convenient, as it required less cognitive load. In contrast, manual operation users had to judge Dofbots' position by themselves through gestures and video, which required more effort and attention. Additionally, controlling the bots through software and hardware delay may have further contributed to the higher workload. The color recognition group, on the other hand, had a simplified operation process without these issues.

In the same experiment situation, we also got the overall performance of task load results from the NASA-TLX questionnaire, which contains the difference between the two groups. The values that reflect the overall performance of the color recognition group are significantly lower than the normal group (including the mean, maximum, minimum, 25%, and 75% quantile). Each of those values is 2 to 3 points lower than the normal group's, which proves the H_4 is reasonable. Additionally, by cross-analysis, we found more than 90% people who give a high mark to overall performance also give a high mark to the relative usability research about the system in the SUS questionnaire. These facts support that using the automatic system can significantly decrease participants' synthetically cognitive burden.

The color recognition group can have higher thresholds for two reasons. One is because the automatic mechanical arm can follow the program's instructions directly to finish a list of work. However, for the normal group, participants need to finish two works, including estimating color and Operating machinery. Moreover, the robotic arm's position is needed to be continually adjusted to carry out a specific task in the experiment. This process constantly depletes the patience and energy of the participants. The other reason is that facing an unfamiliar set of equipment, the normal group needs time to learn the theory of the machine and how to operate the system correctly, but for an automatic system, it is not a must.

VI. Discussion

A. How do we design the human-robot collaboration?

Our group is working on using cluster robots to collaborate with people to solve problems. For example, they can be applied in areas as diverse as search and rescue, aerial surveillance and data gathering, robotic assistants, and autonomous systems operating on land, sea, air, or outer space. We have studied and analyzed the systems and controls of the robot. To achieve control of groups of robots, we have studied some basic functions, such as visual recognition and robotic pick-and-place. These functions are combined as a complete system, helping robots to collaborate. Our main result is an adaptable human-computer interaction system. The HRI unit using this as a template can be extended to other applications such as assembly line processes. During the discussion, we will compare our study results with earlier studies and explain our findings and contribution. Besides, the limitation and further possibilities will be proposed.

Our developed system differs from distributed robot systems and offers greater flexibility. In contrast to the fixed assembly lines found in most factories, we have designed a system that can be scaled up to a specific size as a cell, depending on the requirements. Groups of robots acting according to this system can work in more situations than if they were stationary and immovable. Our developed system differs from distributed robot systems and offers greater flexibility. In contrast, our group is working on the question of assembly lines found in most factories; we have designed a system that can be scaled up to a specific size as a cell, depending on the requirements. Groups of robots acting according to this system can work in more situations than if they were stationary and immovable.

B. The relationships between robotics design and human work practices

To discuss our activities in the project, we critically reflect on our role: to what "inside" did we belong? We were insiders in the research institute; however, we did not represent engineering perspectives and interests or work under any principles as we were taught in schools. Instead, we most likely scope idea exchange through the research insights to seek a mutual benefit or alter of activities for a common purpose among the project stakeholders. That means we acknowledge the insights from the workers on the front line who use robots during their daily work practices in industries. We created a coalition between the workers in the industries, the research institute, and the engineers (us) to work cooperatively on initiating the research design. Thus, we increased the ownership of the common interest in the project and thereby had the chance to extend this interest to increase commitment from the research institute and the industries. To this end, we were outsiders on the project, which increased the trust between the people who use and own those robots in workplaces and us; thus, we could access its power to shape participation. Through open dialogues in development processes, a communicative ecology was developed among the participants to enhance each other's capacity for mutual benefit and common interest.

Additionally, by actively stepping in and out of design and development work, our animated actions in the project made the people follow how we conduct human-centered HRI research. Such a research culture expanded our modus operandi with technology design and used in industrial contexts. It still seems we are not only helping to make different actors' practical actions accountable in and through their member groups when addressing robot system design, but we also seek and ensure a reasonable win-win situation would exist in any contextualization of the long-term consequences of human-robot collaboration at work.

C. Reflective methodology

The methodology we deployed provides fruitful insights for designing the relationships between robots and humans. For us, through observation of the work practices of work practices in the industrial contexts, the participants' responses indeed provided feedback for the project; we could help to explore other meanings instead of only robot design. However, our insider and outsider positions in the project, which necessitated people to plan, work, observe, and reflect on technology design, cannot bring a brighter future for workers in the long run. We realized that our analysis and our positions that the project may create political issues about securing jobs could be questioned; that it might be beyond our capabilities to handle; however, there are many ways to research to analyze ICT projects. Every project has its own challenges and opportunities, and the resources provided vary. In the present work, what works particularly well is the case where projects seriously attempt to develop a "research culture" to include "dialogue" and to acknowledge it as an inclusive, useful, and participatory activity. In that light, we would argue that this paper allows room for researchers in various domains with similar obstacles as we faced to investigate further the notion of participation and possible ways to re-balance the power relations.

D. Creativity of the current project

That sounds like a very promising application of swarm robots in the assembly line. By using cameras and machine vision, the robots can work together more precisely and effectively, while engineers can monitor their performance in real-time. This not only improves the safety and efficiency of the assembly line, but also provides valuable data for continuous improvement and optimization. Furthermore, by using a small number of robots as work units, it can be a cost-effective solution for low-margin and simple manufacturing industries. Overall, this project has great potential to transform the manufacturing industry and improve the work environment for both robots and humans.

Using aruco markers as the objective points for the robot arms is an innovative approach that has several advantages. Firstly, it simplifies the programming required for the robotic arms to grab and place objects, as they only need to recognize the aruco marker and follow its position. This makes the system more efficient and easier to use, as it reduces the complexity of the programming required. Secondly, aruco markers are highly accurate and reliable, which improves the precision of the system and reduces the risk of errors or accidents. Finally, aruco markers are easy to install and use, which makes them a practical and cost-effective solution for industrial applications.

By analyzing the data on how the system performs in different environments, we can further fine-tune the system to optimize its performance and increase its effectiveness. This will help us identify any potential issues or limitations of the system and find ways to overcome them. Overall, using aruco markers as the objective points for the robot arms is a promising approach that has the potential to improve the efficiency, accuracy, and safety of industrial assembly line operations.

E. General Criteria for Human-Robot Collaboration in Industrial

In such cases, industrial swarm robots can be a potential solution as they can work in a flexible, adaptive, and efficient manner. Another criterion is that the system's cost should be lower than or comparable to the cost of using traditional methods. The economic feasibility of the system must be carefully evaluated before implementation. Furthermore, the system must be able to work safely and reliably in the industrial environment, with minimal risk to workers or damage to equipment. The system should also be easy to operate and maintain to ensure its long-term viability. Additionally, the system should improve the overall efficiency of the production process, reduce downtime, and increase output. Finally, the system should be scalable and adaptable to different production scenarios and environments. It should be able to handle different types of products and be easily integrated into existing production lines. The application of industrial swarm robots in solving real-world industrial problems requires careful evaluation and consideration of various criteria to ensure its effectiveness and viability [19].

Once we determine the optimal application environment for human-robot collaboration in the industry, we must consider whether the problem needs the technology. The key to analyzing a problem is if can break it up into several smaller problems. Different units do multiple small tasks at the same time to increase efficiency. However, we'd better change our idea when facing a problem that can't be divided. For example, in the automobile assembly line, the whole line is based on combining different car parts such as frames, wheels, and various connections. During the process, the cotbot assembly line may be more suitable for this mode of production.

F. Future work

For the whole experiment, we employ two main actions, including robotic arm grasping and mechanical vision color recognition.

For color recognition, though we apply the HSV color model to improve the precision as soon as possible when the experiment is taken in different places, engineers need to calculate the HSV information affected by various factors such as light intensity and ambient color. This is tedious and time-consuming work. Moreover, in recent years, deep learning-based recognition algorithms are getting more and more sophisticated. In our future work, we can apply a deep-learning model to color recognition. With the help of a deep learning model, even if on some occasions with indistinct features, various shapes, and chaotic scenes, the technology can make up the disadvantages of traditional color recognition, such as failure to recognize object color and causing confusion between object and environment.

For the robotic arm grasping, the robotic arm we used in the experiment is the DofBot Raspberry PI vision robot arm that has six degrees of freedom. Most industrial robots we can see in the market are six-axis, but from the ergonomics perspective, the seven-degree-of-freedom robotic arm is closer to the structure of the human body. Furthermore, the robotic arms with seven degrees of freedom are more sensitive and can naturally perform more human-like movements, such as twisting the key. In some complex situations, the seven-degree-of-freedom robotic arms can also adapt better and adjust their steering engines according to the needs of the environment.

VII. Concluding Remarks

The present study was undertaken to design robots that engage in HRI and can be adapted to a collaborative human-robot control system. We detail the design process of this robot and discuss its possible directions and applications in light of the current situation. We discuss the design thinking behind robots and their role in HRI. Our work brings in the researcher's perspective and conceptualizes the implications of utilizing robots in an industrial setting. The research result shows that our design sheds insights for deploying robotic systems with a human-in-the-loop perspective to aid assembly tasks. Apart from this pioneering idea, we assert our work can add literature to the human-robot interaction field.

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