A review of manufacturing systems for introducing collaborative robots

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Abstract—**Industry 4.0 highlights a new industrial revolution for the manufacturing system. This work aims to provide a review of different types of manufacturing systems and present motivations of introducing collaborative robots into manufacturing. We start with a discussion about the existing research of human-robot collaboration as well as its perception and control strategies. Then, we give a review of the current applications of swarm robots in manufacturing. Finally, we propose some insights for future directions of human-robot society.**

Index Terms—**manufacturing system, human-robot collaboration, swarm robotics, cognitive model**

I. INTRODUCTION OF MANUFACTURING SYSTEM

The manufacturing system, which is defined as a collection of labour resources and integrated equipment, is utilized to process and assemble the raw production materials [1]. In this section, five types of manufacturing systems are discussed and compared. We also present the features and potential robot usage of them as shown in Table I.

Flow shop is a product-oriented system while scheduling the sequence of order is difficult. Sadik and Urban [2] introduced a case study which optimizes the scheduling problem with Human Robot Collaboration (HRC). Cellular manufacturing which groups similar parts into families and assigns the associated machines located in each cell into groups [3] implements the small scale to produce part of a production with one worker in [4]. Its people-oriented character emphasizes the human operator's versatility and flexibility. However, to improve production efficiency, robot assistance should be added into the system as another step. Flexible manufacturing system (FMS) is defined as a production method which is adaptable for production type and size. Krüger et al. [5] proposed Intelligent Assist Systems for more flexible assembly tasks. Reconfigurable manufacturing system (RMS), combining the flexibility of FMS with the high throughput of a dedicated manufacturing system, is designed for adapting to the rapid changes of the market within the same part family. The project shop aims for large scale products which require multiple components in the layout like aeroplane manufacturing. Bauda et al. [6] proposed 'Air-Cobot robot' for vision inspecting of production quality.

TABLE I
MANUFACTURING SYSTEM

Manufacturing system	Features	Potential cobot usage
Cellular manufacturing	High product variation Highly skilled labour	Task-based HRC to improve efficiency
Flexible manufacturing	High product variation Highly skilled labour	Intelligent assist system for the variate product
Flow shop	Low product variation Low skilled labour	Solving scheduling problem and manual labour shortage
Reconfigurable manufacturing	Customized flexibility Adaptability	Reconfigurable machine tools
Project shop	Large products Low variation	Air-Cobot for vision inspection

II. COLLABORATIVE ROBOT IN MANUFACTURING SYSTEMS

A. *Industrial tasks for human-robot collaboration*

The main advantage of human-robot collaboration in the manufacturing system is that robots can assist human operators with sophisticated tasks. In this manner, machines do not replace humans, but they supplement their ability by getting rid of heavy work for workers. Unlike the traditional industrial robots, collaborative robots (cobots) in the manufacturing system can offer more safety and dexterity. Such Robots, for instance, rethink or universal robots, can combine the precision and speed of machines with the proportions and flexibility of human hands. Another feature is that the robot can learn from demonstration due to its simplification in programming for specific tasks.

To allow the robot to better understand the human, several perceptions are utilized to collect external data to the internal representation system. Robot vision combines the camera and software toolkit to enable the robot to obtain visual data from the world and execute responding physical actions [7],[8],[9]. The impedance control is used to measure the force between the manipulator and human, and hence infer the relationship between the force and position [10],[11]. Audition, as sounds or voice, is another common modality which can be used to guide intelligent system or communication [12].

In manufacturing tasks nowadays, the cobot becomes more competitive when compared with the human operator and traditional industrial robots. Many manufacturers are eager to adopt HRC technology to enhance the effectiveness and flexibility of their production. Table II demonstrates some industrial scenarios working with cobot.

As seen in the table, the main tasks where cobots are involved with the industry are manual assembly tasks. The human operator is able to operate variant productions while the work-ability can be restricted by ergonomic factors and hence influence the accuracy and production volume [13]. Traditional industrial robots can handle high repetitive and payload tasks, for instance, the ABB IRB 7600 can handle up to 500kg materials [14]. However, in complex manual assembly tasks, it is too expensive to achieve and dangerous to human operators [15]. The cobot can combine the repeatability from industrial robots and flexibility from workers. Meanwhile, as the safety control strategy of cobot is designed for operating among humans, it can also save work space [16].

TABLE II
SOME STATE-OF-THE-ART IN USING COBOT FOR INDUSTRIAL TASKS

Industrial scenarios	**Tasks**	**Advantages**
BMW[17]	Equipping insulation insider door	Replace human worker
Audi[16]	UR3 cobot for adhesive on car roof	Save space
Volkswagen[13]	KuKA cobot for screwing on drive train	Easier to reach locations
ARM[18]	Prepreg for composite layup	Reduce human operator's workload

III. SWARM ROBOTS IN MANUFACTURING SYSTEM

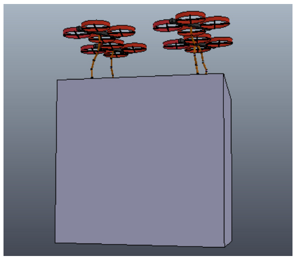
Fig. 1. Cooperative transportation

The industrial robots have been successfully deployed in manufacturing for the last decades. They can be represented by the static robot arms which are programmed to execute the heavily manual, complex and hazardous tasks. However, the setup of the layout and the controller for these inflexible machines often cost much time and money when the design of the product changes. Thus, mobile robots like unmanned ground vehicle (UGV) and unmanned aerial vehicle (UAV) with good maneuverability can be appropriately utilized to make a difference. Moreover, as the manufacturing environment is dynamic and uncertain, we cannot expect one single robot to fulfil all the tasks. Therefore, to enhance the efficiency and robustness of the system, the concept of swarm robotics which is inspired by the collective behaviours of social insects can be introduced. The swarm engineering [19] aiming at overcoming the current limitations of swarm robots is also addressed to make the robot team collaboratively solve the real-world challenges in manufacturing.

Although the swarm robots already make some achievements on the surveillance, mapping and navigation, the applications in the industry mainly focus on the manipulation [20], transportation [21], and assembly. A team of drones transportation scenario is shown in Fig.1. In [22], the authors develop a new tool which is capable of co-localizing holes and fasteners for robust insertion and fastening. In the experiment, a heterogeneous team of four robots with different skills are assigned to align and fasten a panel to a corresponding box. The transportation of materials is achieved in [23] using neural network synthesised by an evolutionary algorithm and [24] using the leader and follower scheme. Another application where swarms have been used is logistics as well as the sorting task in the warehouse. As self-organisation is a well-known behaviour of swarm intelligence, collective behaviour is explored for the autonomous goods classification using ground robots in the real world. In [25], controlled by the neural network, the swarm of agents called ants are evolved to perform the patch sorting and annular sorting for the objects with different shapes in the environment. Currently, aerial robots haven't been massively deployed in the factories due to the problem of stability and battery life except for the project shop manufacturing system. For example, in the shipbuilding or aircraft assembly industry, as the position of the layout is fixed, the material components can be transported into the product by the aerial swarm [26].

IV. CONCLUSION AND FUTURE PLAN

From the previous review of the collaborative robot, it is observed that the cobot can combine the repeatability and flexibility from industrial robot and human operator to enhance the production efficiency. However, in the existing cobot application scenario, most of them are task-based and operated in constrained static environments. Moreover, the material and information flow of the manufacturing system is often a problem [1]. For instance, in a project shop, the work may be interrupted if the material supply is late. The potential solution can be the combination of swarm robots and static robots. For instance, if the static cobot can sense the current workflow and any absence of components based on its cognitive architecture, it will inform the swarm robots of the transportation task. In this manner, the manufacturing system will become more automatic. This paper investigates and analyzes the current and potential applications of collaborative robots in manufacturing systems. To deal with the uncertainty of the market, increasing the automation level of the system by a massive deployment of the robots in factories is no longer the priority. It might be necessary to pay more attention to human-robot and robot-robot interactions so that robots can be easily reconfigured to collaborate better with the human, which makes the manufacturing system move closer towards the standard of Industry 4.0.

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REFERENCES

[1] T. Vamos, "Automation production systems and computer integrated manufacturing. Mikell P. Groover," *Automatica*, vol. 24, no. 4, p. 587, 1988.

[2] A. R. Sadik and B. Urban, "Flow shop scheduling problem and solution in cooperative robotics—case-study: One cobot in cooperation with one worker," *Future Internet*, vol. 9, no. 3, 2017.

[3] Y. Yin and K. Yasuda, "Similarity coefficient methods applied to the cell formation problem: A taxonomy and review," *International Journal of Production Economics*, vol. 101, no. 2, pp. 329–352, 2006.

[4] J. T. C. Tan, F. Duan, Y. Zhang, K. Watanabe, R. Kato, and T. Arai, "Human-robot collaboration in cellular manufacturing: Design and development," *2009 IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS 2009*, pp. 29–34, 2009.

[5] J. Krüger, R. Bernhardt, and D. Surdilovic, "Intelligent assist systems for flexible assembly," *CIRP Annals - Manufacturing Technology*, vol. 55, no. 1, pp. 29–32, 2006.

[6] M.-a. Bauda, A. Grenwelge, S. Larnier, M.-a. Bauda, A. Grenwelge, S. Larnier, M.-a. Bauda, A. Grenwelge, and S. Larnier, "3D scanner positioning for aircraft surface inspection To cite this version : 3D scanner positioning for aircraft surface inspection," 2019.

[7] B. Teke, M. Lanz, J. K. Kämäräinen, and A. Hietanen, "Real-time and Robust Collaborative Robot Motion Control with Microsoft Kinect ® v2," *2018 14th IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications, MESA 2018*, pp. 1–6, 2018.

[8] F. Fang, Q. Xu, Y. Cheng, L. Li, Y. Sun, and J.-H. Lim, "Self-Teaching Strategy for Learning to Recognize Novel Objects in Collaborative Robots," pp. 18–23, 2019.

[9] K. T. Song, Y. H. Chang, and J. H. Chen, "3D vision for object grasp and obstacle avoidance of a collaborative robot," *IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM*, vol. 2019-July, pp. 254–258, 2019.

[10] L. Rozo, S. Calinon, D. G. Caldwell, P. Jiménez, and C. Torras, "Learning Physical Collaborative Robot Behaviors From Human Demonstrations," *IEEE Transactions on Robotics*, vol. 32, no. 3, pp. 513–527, 2016.

[11] E. C. Townsend, E. A. Mielke, D. Wingate, and M. D. Killpack, "Estimating Human Intent for Physical Human-Robot Co-Manipulation," 2017. [Online]. Available: http://arxiv.org/abs/1705.10851

[12] P. Gustavsson, A. Syberfeldt, R. Brewster, and L. Wang, "Human-robot Collaboration Demonstrator Combining Speech Recognition and Haptic Control," *Procedia CIRP*, vol. 63, pp. 396–401, 2017. [Online]. Available: http://dx.doi.org/10.1016/j.procir.2017.03.126

[13] KUKA, "Many wrenches make light work: KUKA flexFELLOW will provide assistance during drive train pre-assembly," 2016. [Online]. Available: https://www.kuka.com/en-de/press/news/2016/10/vw-commits-to-human-robot-collaboration-in-wolfsburg

[14] ABBRobotics, "IRB7600 Opening a new world of possibilities," 2019. [Online]. Available: https://new.abb.com/products/robotics/industrial-robots/irb-7600

[15] M. Hägele, W. Schaaf, and E. Helms, "Robot assistants at manual workplaces - Effective co-operation and safety aspects," *Proceedings of the 33rd International Symposium on Robotics (ISR)*, p. 6, 2002.

[16] Audi, "New human-robot cooperation in Audi production processes," 2015. [Online]. Available: https://www.audiusa.com/newsroom/news/press-releases/2015/02/new-human-robot-cooperation-in-audis-production-processes

[17] N. Giles and M. Hatzel, "Innovative human-robot cooperation in BMW Group Production," 2013. [Online]. Available: https://www.press.bmwgroup.com/global/article/detail/T0209722EN/innovative-human-robot-cooperation-in-bmw-group-production?language=en

[18] Advanced Robotics for manufacturing, "ROBOTIC ASSISTANTS FOR COMPOSITE LAYUP," 2020. [Online]. Available: http://arminstitute.org/projects/robotic-assistants-for-composite-layup/

[19] R. T. Anderson, L. Neri, R. T. Anderson, and L. Neri, "Swarm Engineering," *Reliability-Centered Maintenance: Management and Engineering Methods*, no. May, pp. 97–206, 2000.

[20] D. Mellinger, M. Shomin, N. Michael, and V. Kumar, "Cooperative grasping and transport using multiple quadrotors," *Springer Tracts in Advanced Robotics*, vol. 83 STAR, pp. 545–558, 2012.

[21] V. Spurny, M. Petrlik, V. Vonasek, and M. Saska, "Cooperative Transport of Large Objects by a Pair of Unmanned Aerial Systems using Sampling-based Motion Planning," *IEEE International Conference on Emerging Technologies and Factory Automation, ETFA*, vol. 2019-Septe, pp. 955–962, 2019.

[22] M. Dogar, R. A. Knepper, A. Spielberg, C. Choi, H. I. Christensen, and D. Rus, "Multi-scale assembly with robot teams," *International Journal of Robotics Research*, vol. 34, no. 13, pp. 1645–1659, 2015.

[23] R. Groß and M. Dorigo, "Towards group transport by swarms of robots," *International Journal of Bio-Inspired Computation*, vol. 1, no. 1-2, pp. 1–13, 2009.

[24] T. Sugar, "Control and coordination of multiple mobile robots in manipulation and material handling tasks," *Experimental Robotics VI*, 2000. [Online]. Available: http://www.springerlink.com/index/P8U250420L347P12.pdf

[25] V. Hartmann, "Evolving Agent Swarms for Clustering and Sorting," pp. 1–8, 2005. [Online]. Available: papers://82ac23f7-2eaf-4339-a5e1-4600c19d7f01/Paper/p2524

[26] Q. Lindsey, D. Mellinger, and V. Kumar, "Construction of cubic structures with quadrotor teams," *Robotics: Science and Systems*, vol. 7, pp. 177–184, 2012.