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SURVEY PAPER

Assembly Challenge: a robot competition of the Industrial Robotics Category, World Robot Summit – summary of the pre-competition in 2018*

Yasuyoshi Yokokohji[a], Yoshihiro Kawai[b], Mizuho Shibata[c], Yasumichi Aiyama[d], Shinya Kotosaka[e], Wataru Uemura[f], Akio Noda[g], Hiroki Dobashi[h], Takeshi Sakaguchi[i] and Kazuhito Yokoi[b]

[a]Department of Mechanical Engineering, Graduate School of Engineering, Kobe University, Nada-ku, Kobe, Japan; [b]National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan; [c]Department of Robotics, Faculty of Engineering, Kindai University, Higashi-Hiroshima, Japan; [d]Faculty of Engineering, Information and Systems, University of Tsukuba, Tsukuba, Japan; [e]Graduate School of Science and Engineering, Saitama University, Saitama, Japan; [f]Department of Electronics and Informatics, Faculty of Science and Technology, Ryukoku University, Otsu, Japan; [g]Department of Robotics, Faculty of Robotics and Design, Osaka Institute of Technology, Osaka, Japan; [h]Mechatronics Major, Faculty of Systems Engineering, Wakayama University, Wakayama, Japan; [i]Intelligent Systems Research Institute, National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan

ABSTRACT
The World Robot Summit (WRS) is a robotic 'challenge and exposition' organized by the Japanese government to accelerate social implementation, research and development of robots working in realistic daily life, society, and industrial fields. In this paper, we introduce a robot competition of the Industrial Robotics Category of the WRS, called 'Assembly Challenge', which is organized by the WRS Industrial Robotics Competition Committee in order to promote the development of the next-generation production systems that can respond to new production demands in agile and lean manners. Prior to the main competition in 2020, a pre-competition was held in 2018 with 16 participating teams from around the world. In this paper, we introduce the contents and results of this pre-competition, analyze the results, and give a perspective for the 2020 main competition.

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Assembly; cell production system; robot competition; agile and lean manufacturing

1. Introduction

The World Robot Summit (WRS) [2] is a robotic 'challenge and exposition' organized by the Ministry of Economy, Trade and Industry (METI) and the New Energy and Industrial Technology Development Organization (NEDO). It aims to accelerate social implementation, research and development of robots working in realistic daily life, society, and industrial fields by bringing together the excellence in robotics from around the world, in order to promote a world where humans and robots successfully live and work together, based on the 'Japan's Robot Strategy' formulated in 2015 [3].

The main event of the WRS is scheduled to be held in 2020, the year of the Olympic Games. Before that, the WRS 2018 was held in Tokyo from 17 to 21 October 2018 at the Tokyo Big Sight as a pre-convention.

The WRS consists of the robot competition called 'World Robot Challenge' and the exposition that displays the latest robot technology called 'World Robot Expo'. The competition has four categories such as 'manufacturing (or industrial robotics)', 'service', 'infrastructure and disaster response', and 'junior'.

Among them, in the Industrial Robotics Category of the WRS, a robot competition called 'Assembly Challenge' is organized by the Industrial Robotics Competition Committee of the WRS, in order to promote the development of the next-generation production system, with the catchphrase: 'Toward agile one-off manufacturing'. The authors have been designing and organizing the competition 'Assembly Challenge' as the key members of the Industrial Robotics Competition Committee.

In this paper, we first describe what the Industrial Robotics Category of the WRS aims for and introduce the details of the competition rules followed by the results of the pre-competition held in Tokyo in October 2018. Finally, we describe the prospects for the WRS 2020 main competition.

2. Brief history of Assembly Challenge

2.1. Background of Industrial Robotics Category

Industrial robots are said to be 'semi-completed products' because they do not function as a single robot and

CONTACT Yasuyoshi Yokokohji yokokohji@mech.kobe-u.ac.jp Kobe University, 1–1, Rokkodai-cho, Nada-ku, Kobe, Hyogo 657-8501, Japan
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Table 1. Levels for the next-generation production system (draft version).

	Aspects during setup changes		Aspects during operation	
	Agility	Leanness	Utilization rate improvement	Remarks
Level 5	0 day for new product (Changeover on the same day)	100% continual use (Introduction of universal hands that are able to perform jig-less assembly for multiple products, etc.)	Machine learning (Temporal stoppage prevention/cycle time improvement)	Ultimate goal
			Fully automated recovery (Even big stoppages)	Autonomous motion planning, etc.
Level 4	2 days for new product (Changeover on a week-end or an overnight business trip)	Available for new products only by recombining existing equipment. (Universal hands able to grasp multiple products, etc.)	Automatic recovery from temporal stoppage (Learning through observing human intervention, etc.)	Target level at WRS
			Human intervention is required for big stoppages.	Small number of universal hands
Level 3	1 week for new product (Changeover in a week, e.g. during large consecutive national holidays)	50% or more can be reused. (Utilization of specialized hand library, flexible jig, multi arms, etc.)	Operation rate improvements (Prevention measures against temporal stoppages, etc.)	Offline planning
			Automated proposals of improvements	Reduction of specialized tools with multiple arms, etc.
Level 2	1 month for new product	Reusing only robots	Reduction of temporal stoppage rate by absorbing part variations using sensors	Levels possible with current technologies
Level 1	For specific products only (Changeover is not assumed.)	0% (No reuse is assumed.)	Controls parts variations to ensure an enough utilization rate. Human intervention is required for temporal stoppages	Many robot systems used today

can only be functional after being integrated with hands and peripheral devices. The cost of the robot itself is only about 20% to 30% of the total cost for robot installation. Besides the cost of peripheral devices and peripheral equipment, the cost of system integration to combine them is more than 50% of the total cost [4].

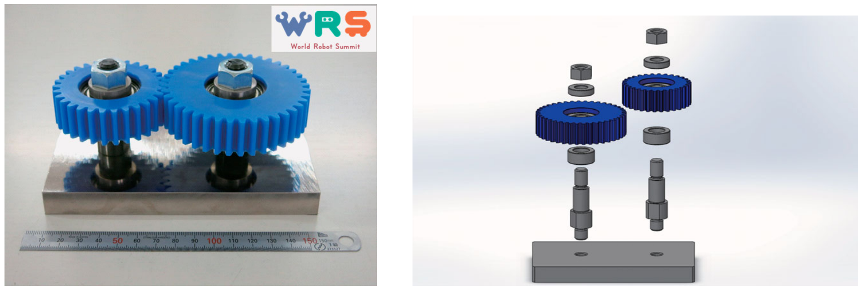
In the era of mass production, even if a lot of effort and cost were needed at the installation stage of a robot, the introduction cost could be paid by continuing to use it for several years, once it was assembled as a system. However, such a system cannot easily meet the demands of high-mix low-volume production caused by the recent diversification of consumer needs and shortening of product life cycle. As a result, cell production by human came to appear. Also, the high cost for introduction, inflexibility for new production requirements, and the need for specialized expertise in operation are the major reasons why robots have not been introduced in small- and medium-sized enterprises (SMEs).

Among the operations performed by robots, assembly operations are time-consuming and costly in preparation of peripheral devices such as parts feeders and jigs and careful teaching is necessary for precise parts fitting. It also takes a lot of time and effort for fine-tuning the robot trajectory in order to eliminate temporal stoppages that tend to occur frequently immediately after the introduction. Besides, in the first place, flexible parts cannot be assembled well by teaching and playback, and the robotization for handling such parts itself has not been realized yet. Therefore, in the Industrial Robotics Category of the WRS, we decided to set 'assembly' as the competition task among a lot of tasks in manufacturing domain.

2.2. Main goal setting

In designing the competition for product assembly, we decided to set up the basic problems for future production systems. Considering the above background and referring to the literature in Europe and the United States [5,6], we concluded that the future robots in the field of manufacturing are required to respond promptly to new production demands without wasting resources, that is, agility and leanness. In response to this, five levels for the next-generation production system have also been drafted as shown in Table 1 in order to clarify the direction in which the WRS should aim. Table 1 focuses on not only the aspects during a setup change but also the aspects during the operation because the efficiency of production remains important even for the next-generation production systems. However, the importance of production efficiency will decrease relatively as the frequency of setup changes increases.

After clarifying the direction to be aimed for as mentioned above, we set the basic form of the competition in such a way that participating teams can compete on the performance of their robot systems that can automatically generate the operation procedure immediately from given product information and recognize,



(a) (b)

Figure 1. Gear unit. (a) Overview and (b) exploded diagram.

grasp, and assemble various parts including flexible parts. Ultimately, we aim at an agile and lean system where efficient manufacturing is possible even for one-off products by quickly reconfiguring the system without teaching or jigs. In addition, the direction of the competition was expressed in an easy-to-understand phrase as 'Toward agile one-off manufacturing'. The competition was named 'Assembly Challenge'.

2.3. Milestones

Prior to the pre-competition in 2018, a trial competition in the Industrial Robotics Category of the WRS was held as a part of the tasks in the Manufacturing Track of the 2nd Robotic Grasping and Manipulation Competition in IROS 2017 held in 26 October 2017 [7], where a gear unit shown in Figure 1 was assembled.

We designed the gear unit just for this trial competition. The number of parts of this gear unit is 11, as can be seen from Figure 1, and all parts are available from MISUMI Group, Inc. The total cost of the parts is around 17,000 JPY. In particular, the fit between the shaft and the bearing inside the gear is an intermediate fit (from 0.002[mm] tight fit to 0.017[mm] gap fit, according to the tolerances information of each part), and parts mating is difficult even for humans. We supplied a complete set of parts of the gear unit in advance to all participating teams of the competition. Because all of the parts are available from MISUMI Group Inc. which has sales sites around the world, we expect that this gear unit can be used as a benchmark for assembly tasks by robots.

The task consists of the following three subtasks: [Subtask 1] Fasten roller bolts on the base plate (85 points), [Subtask 2] Insert metal collars and gears (130 points), and [Subtask 3] Secure gears with nuts (85 points). The total score of this task is 300 points. Each subtask starts from a given initial condition so that teams that failed to complete the previous task can move on to the next subtask.

Six teams registered to the Manufacturing Track, but only four teams actually participated in the competition. The maximum points among these teams were 142, meaning that no team could assemble the gear unit perfectly.

After the trial competition, we held a demonstration competition at the NEDO booth of the International Robot Exhibition held at Tokyo Big Sight in December 2017.

Since the Assembly Challenge was a completely new robot competition, we could learn a lot about rule making and competition judgment by the trial competition. In addition, we could get a lot of knowledge about how to direct the competition and how to secure the safety of the spectators in the demonstration competition. These two events were valuable experiences for us in designing the pre-competition in 2018. Figure 2 shows the milestones of the Assembly Challenge. The rules for the 2018 pre-competition will be detailed in the next section.

2.4. Related robot competitions and benchmarks

In this section, we review the existing benchmarks and challenge programs related to assembly. Please refer to the survey paper [8] which is coauthored by one of the authors for details.

2.4.1. Benchmarks

In 1984, Collins et al. proposed Cranfield benchmark for comparing robot programming for assembly [9]. Recently, researchers at Yale University, Carnegie Mellon University, and the University of California Berkeley jointly proposed YCB Object and Model Set [10]. Falco et al., a group of NIST (National Institute of Standards and Technology), shows a framework for robotic hand performance benchmarking [11].

2.4.2. Challenge programs and competitions

The ARM project of DARPA was a challenge program on manipulation [12]. Also in DRAPA's Robotics Challenge (DRC) Finals, several manipulation tasks including surprise tasks were introduced as indoor tasks [13].

Figure 2. Milestones of the Assembly Challenge.

At the conference site of ICRA 2015 in Seattle, the Amazon Picking Challenge (APC), a robot competition of picking operation, was held [14]. This competition was started because picking operation is still difficult to be automated and has been a bottleneck in logistics. The second APC was held in Leipzig, Germany in 2016 and the third one, renamed as Amazon Robotics Challenge (ARC), was held in Nagoya, 2017, both in conjunction with RoboCup. Amazon.com, Inc. decided to end the ARC with the third one.

In RoboCup, RoboCup@Work [15] has been held from 2012 as a competition of advanced manipulation in industrial applications. RoboCup also has a competition for transporting work for flexible production in the factory by robots called RoboCup Logistics [16]. These two competitions had gone to the same category called RoboCupIndustrial from 2017.

In the EU, a challenge program called EuRoC (European Robotics Challenge) was launched as a four-year project in April 2014 [17], including three industry-relevant challenges, Challenge 1: Reconfigurable Interactive manufacturing Cell, Challenge 2: Shop Floor Logistics and Manipulation, and Challenge 3: Plant Inspection and Servicing. To encourage the collaboration between the industry and academia, EuRoc introduces a unique call for challenger teams consisting of researchers, end users, technology developers, and system integrators. The challenges relevant to grasping and manipulation are Challenges 1 and 2.

In addition to EuRoC, Airbus Shopfloor Challenge [18], which was held at ICRA 2016, and RoCKIn@Work [19–21] are other challenge programs related to the EU. The RoCKIn project including RoCKIn@Work was successfully completed in 2015 and has been inherited by the European Robotics League (ERL) [22] founded by Horizon 2020 framework of the EU.

At the IROS 2016 conference site in Korea, IROS Robotic Grasping and Manipulation Competition [23] was held. The 2nd IROS Robotic Grasping and Manipulation Competition was held in Vancouver, Canada in 2017, where a new track called Manufacturing Track was introduced [24]. The Manufacturing Track has two tasks: Task 1: Assembly / Disassembly Task Board and Task 2: Gear Unit Assembly. As mentioned in Section 2.3, Task 2 corresponds to the trial task of the Industrial Robotics Category of the WRS.

In summary, there have been many robotic challenges relevant to grasping and manipulation. However, none of them requires sophisticated grasping and manipulation which would be necessary in assembly tasks, such as in-hand-manipulation and precise fitting. Probably the Manufacturing Track in the 2nd IROS Robotic Grasping and Manipulation Competition would be the first attempt for such a robotic challenge aiming at sophisticated grasping and manipulation.

Therefore, we expect that the Assembly Challenge in the WRS Industrial Robotics Category can be a unique robot competition aiming at agile and lean manufacturing in a realistic scenario.

3. Design of Assembly Challenge of WRS 2018

3.1. Overview of the challenge

In designing the rules for the 2018 pre-competition, we first examined the product to be assembled. As shown in Figure 2, we designed a belt drive unit which is more difficult than the gear unit designed for the trial competition.

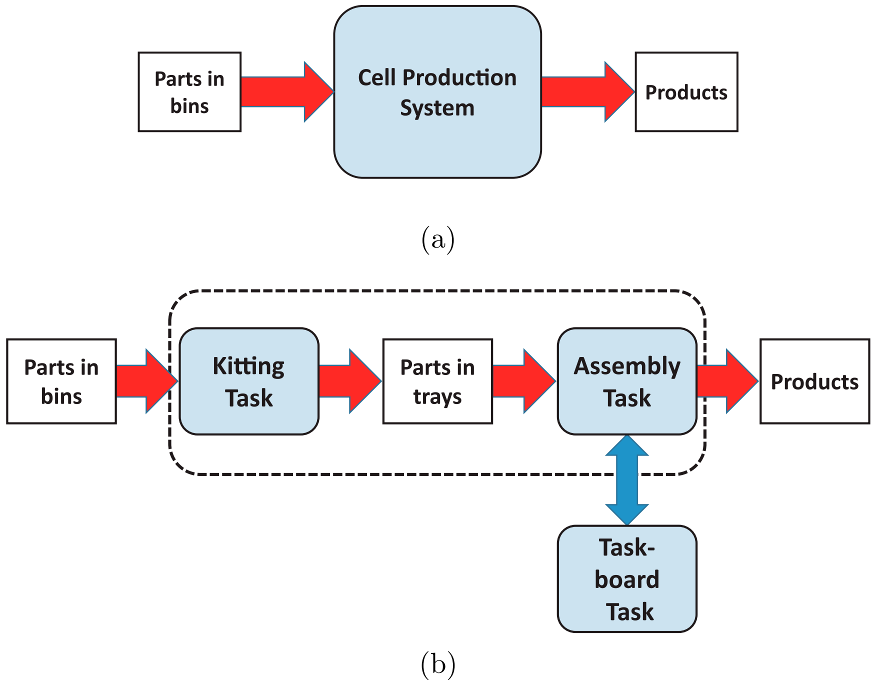


Figure 3. Relationship between a cell production system and each task of the Assembly Challenge in the WRS 2018 (The assembly task starts from a complete parts kit even if kitting is incomplete in the kitting task). (a) Cell production system and (b) tasks of the Assembly Challenge in the WRS 2018.

The difficult points of the belt drive unit compared to the gear unit are; (i) many parts including very small ones such as an M3 set screw, (ii) a flexible part (belt), and (iii) unlike the gear unit, the assembly direction is not always vertical, and (iv) assembly processes that require dual arms, such as assembling one part while holding another part. We also considered to introduce a transparent part such as the cover of the unit which is difficult to be recognized by vision, but gave it up due to the high cost for preparing such a cover. Then, to promote agile and lean manufacturing systems, we decided to introduce surprise parts, i.e. some new components of the belt drive unit that would be disclosed for the first time just before the competition so that the participating teams can compete on how quickly (agile) and slimly (lean) they can deal with new production demands. The details about the surprise parts will be described later.

The ideal form of a robotic assembly system that can quickly respond to the demands of new products is a cell production system. In the current cell production system by human workers, as shown in Figure 3(a), basically one person takes out necessary parts from the parts bins and assembles the product. We concerned that it would be too difficult for the teams to robotize this cell production framework immediately for the competition, and decided to divide it into two, kitting performed as a pre-assembly stage and assembly from the kitted parts, as shown in Figure 3(b). Inspired by the task board which was designed by Van Wyk et al. from NIST [11] and introduced in the IROS 2nd Robotic Grasping and Manipulation Competition, we also introduced a task board which contains assembly elements extracted from the belt drive unit assembly and decided to make it one of the competition tasks.

Not limited to the belt drive unit, but in general, it is necessary to build up the processes one by one in order to assemble a product. If one process is not completed, one cannot move on to the next one and cannot complete the product. With the task-board task, on the other hand, one can easily accumulate the points because all necessary processes are separated. In addition, we expected that it would be suitable as an introductory task, leading to the assembly of the belt drive unit by carrying out the individual items of the task board.

In the following sections, we will explain the competition schedule and the competition field. Then, we will explain in detail the rules of each task, 'task board', 'kitting' and 'assembly'. Please refer to [25] for more details of the competition rules.

3.2. Schedule

Table 2 shows the competition schedule. The participating teams are allowed to enter the competition venue

Table 2. Competition schedule.

October 2018							
15th	16th	17th	18th	19th	20th	21th	22th
Setup days		Day 1	Day 2	Day 3	Day 4	Day 5	Post-competition event
Closed to public		Open to public					Closed session
Team setup		Assembly Challenge					
		Assembly task					
System setup/adjustments, safety and health inspection		Task-board task	Kitting task	w/o surprise	w/ surprise	Exhibition and award ceremony	Symposium

from October 15th, and set up and adjust their robot systems within two days. Once the robot system has been set up, it will be subject to the safety inspection by the Safety and Health Management Committee. Teams are not allowed to participate in the competition without passing this inspection.

The venue is open to the public from October 17th, when the competition begins. The competition ends on Day 4, and Day 5 is for an exhibition with the top winning teams. On the 22nd, a symposium closed to the public is held to receive feedback from the teams and to discuss the competition for the WRS 2020.

3.3. Competition field

Figure 4(a) shows a perspective view of the arena, one unit of the competition field for the Assembly Challenge. As shown in the figure, the arena is a collection of four team areas, each of which consists of a system running area and an operation area. The team's system including robots should run only in the system running area. In the operation area, team members can develop robot programs and monitor their systems during the competition. Figure 4(b) shows an overview of the actual competition field. The competition venue has four arenas A, B, C, and D, resulting in areas for 16 teams in total.

At the competition, four teams play simultaneously, each team from each arena, and the competition is progressed every four teams in turn.

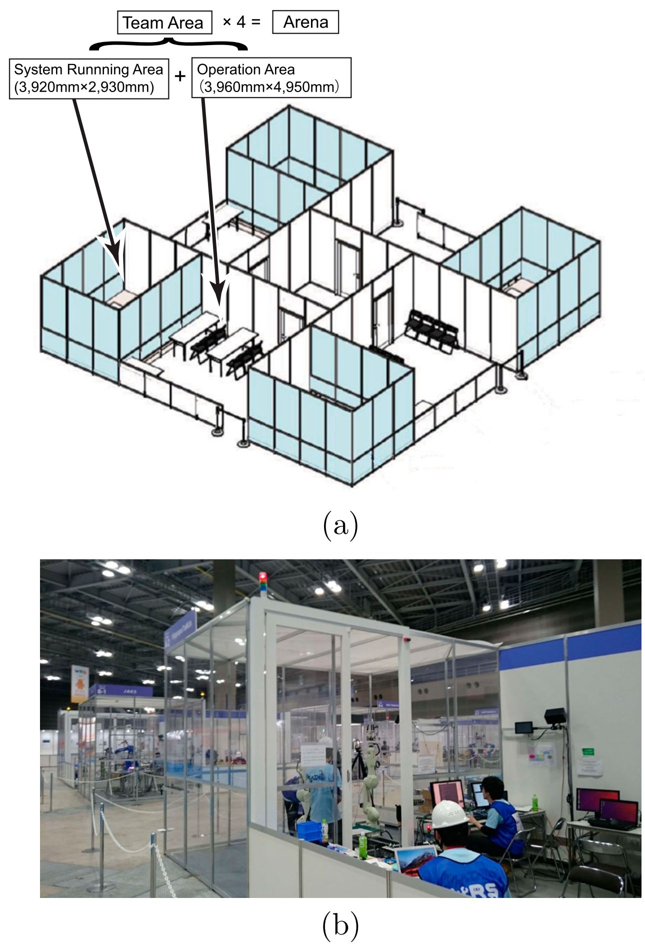


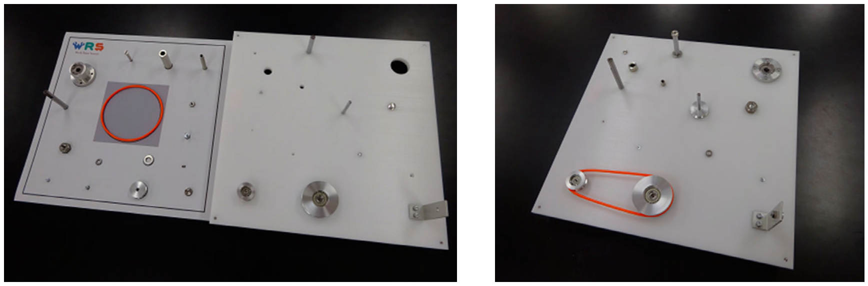
Figure 4. Competition field. (a) Arena and (b) actual competition field.

3.4. Competition rules

3.4.1. Task board

The task board is a collection of 14 tasks extracted from the elementally tasks required in assembling the belt drive unit, which are arranged on a 400mm × 400mm board. This task board was designed with reference to the NIST task board [11]. Detailed information is shown in Figure A1, Tables A1 and A2 in Appendix.

The competition time is 20 min, each team competes twice (Tries 1 and 2) on Day 1, and the one with the higher score is adopted. An overview of the task board is shown in Figure 5. Figure 5(a) shows the initial configuration in which the parts are placed at the designated locations on the placement mat. The layout of the parts on the placement mat is not announced in advance, and is shown for the first time 10 min prior to the start of the competition. This prevents the team from picking parts by prior teaching. Immediately after the start of the competition, the preparation phase begins, and team members can install the task board and the placement mat in the system



(a) (b)

Figure 5. Task board. (a) Initial configuration (placement mat (left) and task board (right)) and (b) completed configuration.

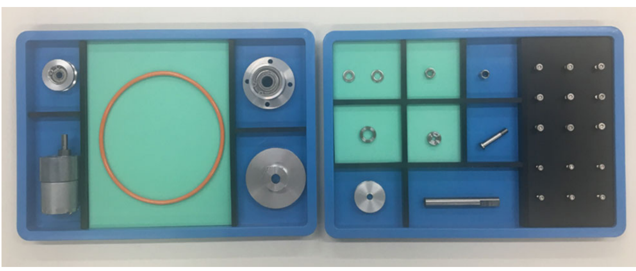


Figure 6. Part-kitting trays with completely kitted parts.

running area, and then place the parts at the designated locations on the placement mat.

When the preparation is completed, the operation phase starts, and the robot assembles the parts on the task board. There are a total of 14 parts to be assembled, and the score is determined according to the completion level of assembly. Table A2 also shows the allocated points depending on the completion level of assembly. Figure A2 shows an example of completion level for Part #8 (M12 Nut). Teams can reset the task any number of times, but it is necessary to return to the initial state each time a reset is declared. The competition time keeps going even during a reset.

The point allocation of the task board is 100 points, and the time bonus described later is separately added if all parts are assembled with completion level 2 or more.

3.4.2. Kitting

We have developed parts trays for kitting (part-kitting trays) as shown in Figure 6 for kitting and assembly tasks. Table A3, Figures A3 and A4 in Appendix show the detailed parts list of the belt drive unit and corresponding part numbers.

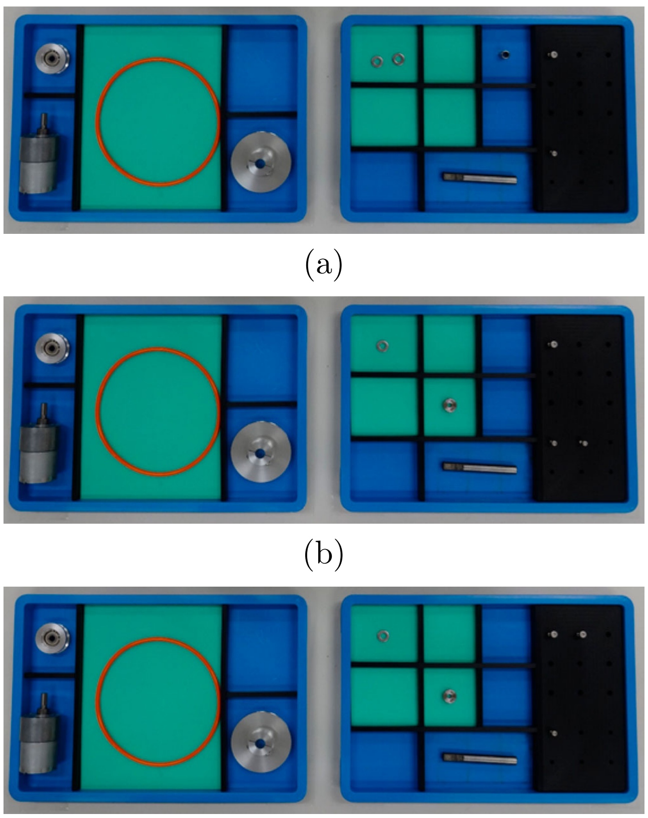
Among the parts of the belt drive unit, 15 types of parts are kitted on two part-kitting trays (parts #4 through #18 in Table A3). Remaining types such as the base plate are large and not placed on the tray. The part-kitting tray was intentionally separated into two trays so that the participating teams can freely arrange the trays in consideration of the motion range of their robots.

At the early stage of competition design, we also considered to let the teams to start from what they actually kitted as is in the subsequent assembly task. In this case, if the kitting is incomplete, the subsequent assembly cannot be completed anyway, and we concerned that the difficulty of the competition becomes too high for the pre-competition. Besides, it is necessary for the teams to prepare parts bin racks or other devices in order to arrange 15 parts bins and two part-kitting trays appropriately inside the limited motion range of the robot. We also concerned that asking such arrangement to the participating teams makes the burden on them more than appropriate for the pre-competition. Therefore, we selected 10 types of parts out of the 15 types for the kitting task so that each team can arrange just 10 parts bins within the motion range of their robots. In the competition, the team must complete three sets of orders each of which requires to kit 10 parts from the selected 10 types of parts.

The competition time is 20 min, each team competes twice (Tries 1 and 2) on Day 2, and the one with the higher score is adopted. Figure 7 shows an example of 10 parts bins and Figure 8 shows an example of completed three sets. As shown in Figure 8, the 10 parts to be kitted may contain the same kind of part. For this reason, three different sets can be ordered from just the 10 types of parts.

A list of three sets of parts is distributed to the team 10 min prior to the start of the competition by an electronic file. At the same time, 10 parts bins containing the corresponding parts and 3 sets of empty part-kitting trays are also provided. However, installation of the parts bins and part-kitting trays in the system running area should be done in the preparation phase after the start of the competition. The team can freely arrange the parts bins and part-kitting trays in the system running area.

Figure 7. Example of 10 parts bins.



(a)

(b)

(c)

Figure 8. Example of three sets of order in the kitting task. (a) Set 1, (b) Set 2 and (c) Set 3.

The point allocation of the kitting task is 50 points for each set, resulting in 150 points in total. Also, if all of three sets of orders are completed within the time limit, the time bonus described later is added separately. The breakdown of the 50 points is 20 points for partial points in total and 30 points as a completion bonus which is added when the ordered set is completed. The completion bonus is introduced considering the fact that kitting is meaningless unless complete kitting is done. Part-kitting trays on which the parts have been kitted must be taken out of the system running area by team members, and only those placed in the designated place outside the system running area are scored. Although a reset is possible any number of times, it is necessary to return all parts for the order currently being processed to the initial state and to start over again each time a reset is declared. The competition time keeps going even during a reset.

3.4.3. Assembly

In the assembly task, teams must assemble the belt drive unit. Appearances and an exploded diagram of the belt drive unit are shown in Figure 9. The drawings are shown in Figure A5 in Appendix.

The belt drive unit consists of 19 types of parts, 33 parts in total. It is assembled from the parts that have been completely kitted on the part-kitting trays by the committee in advance.

On Day 3, teams can try twice (Tries 1 and 2) where two normal units, whose part information has been released in advance, must be assembled in each trial within the competition time of 45 min, and the one with the higher score will be adopted. On Day 4, two normal units and one unit including the surprise parts (three units in total) must be assembled within the competition time of 60 min. Information for the surprise parts is released during the competition period. Although the team may assemble these three units in any order, no points can be earned from the second normal unit if they assembled normal units alone, since the purpose of Day 4 is to compete on the agility for responding to a new production demand. The competition for Day 4 is only once for each team.

The part-kitting trays with kitted parts are provided 10 min before the start of the competition, but the installation of the part-kitting tray in the system running area is done in the preparation phase after the competition starts. The disclosure of information about the surprise parts, CAD models and actual parts, was originally planned to be 60 and 10 min before the start of the competition, respectively. However, CAD models were actually provided 19 h prior to the competition and the actual parts were given 2 h prior to the competition, so that the teams can have enough time for responding to the surprise parts.

The maximum points of Day 3 are 100 points. The breakdown of the 100 points is 45 points (×2) for assembling one unit and 10 points for Agility & Leanness evaluation (mainly technical evaluation on Day 3). The breakdown of the 45 points for assembling one unit is that 31 points in total of points for eight subtasks and 14 points for the evaluation of the assembled product. We divided the assembly process of the belt drive unit into

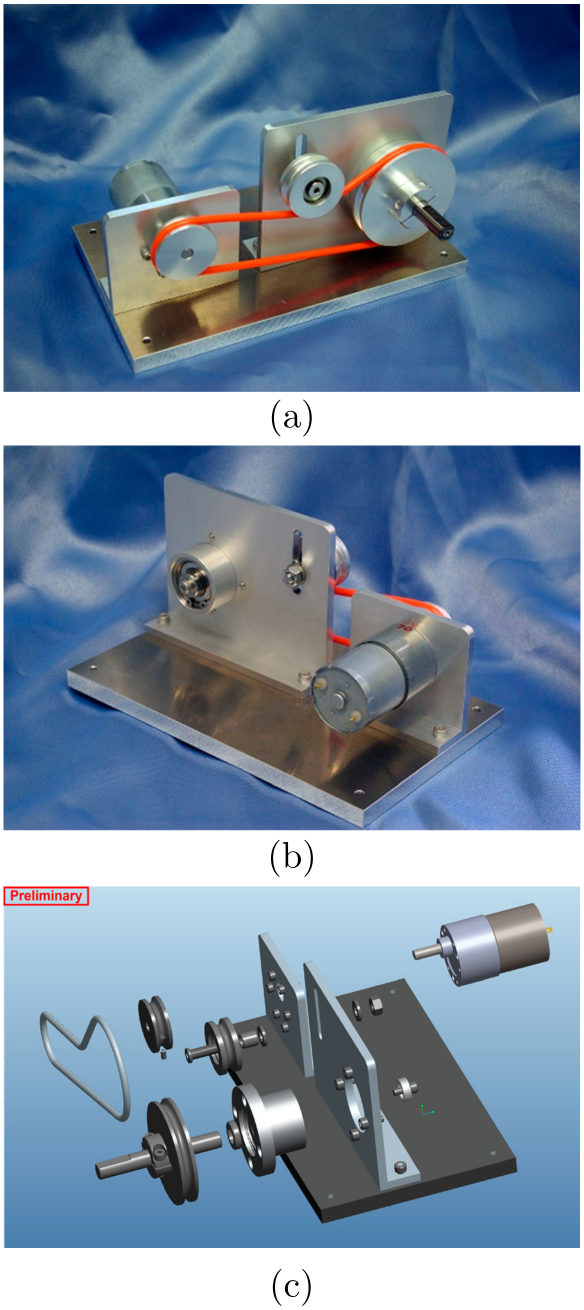


Figure 9. Belt drive unit. (a) Front appearance, (b) rear appearance and (c) exploded diagram.

eight subtasks (Subtask A through H) so that teams can get partial points by completing each subtask. As shown in Table A4 in Appendix, we defined 2 or 3 completion levels for each subtask and assigned points for each level. See Figures A6 and A7 in Appendix for the details of the subtasks and an example of the completion levels.

Besides 100 points, the time bonus described later will be awarded if two units are completely assembled, i.e. all subtasks are completed with completion level 2 or more. Please refer to the rule book [25] for more details.

The points for Day 4 are up to 200 points, and the time bonus is separately added if three units (including the one with surprise parts) are completely assembled, i.e. all subtasks are completed with completion level 2 or more. The breakdown of the 200 points is 45 points ($\times 3$) for assembling one unit and up to 65 points for Agility & Leanness evaluation. On Day 4, Agility & Leanness evaluation includes the evaluation of setup time for responding to the surprise parts and achievement of surprised parts assembly as well as the technical evaluation also done on Day 3.

The belt drive units (or its subassemblies completed in the subtasks) assembled on Day 3 and Day 4 should be taken out by team members from the system running area and only those placed in the designated place outside the system running area are scored. Although reset is possible any number of times, it is necessary to return the parts for at least one of the subtasks currently being dealt with to their initial states at each reset. The competition time keeps going during a reset.

In addition, on Day 4, if the unit including the surprise parts is not completed beyond a certain level, in other words, if the completion level of the subtasks that include surprise parts did not reach at level 1 or more, the points of the second normal unit become invalid. This is a countermeasure to prevent the strategy of completing only two normal units and earning points on Day 4 where we actually require quick setup changes responding to the request of assembling a new unit including the surprise parts.

Figure 10 shows five types of belt drive units including the surprise parts. As shown in the figure, the Agility & Leanness evaluation points are graded, according to the degree of difficulty of the surprise parts. Since the number of surprise parts available is limited, we decided to let each team select one of those types in the order of total points earned until Day 3. In the actual competition, each team took different strategies, such as selecting easy ones to earn consistent points and choosing difficult ones aiming at a large number of points.

3.5. Time bonus

Table 3 shows the points of each task and the total points. Only when certain conditions are satisfied in each task, as explained in Section 3.4, 1 point is added as a time bonus (with an upper limit) for every 20 seconds of remaining time.

The time bonus is awarded up to 50 points in the task-board task. This corresponds to completing the task board in 3 min and 20 s after the start of the competition. In the kitting task, the bonus is added up to 50

Table 3. Point allocation of each task.

Day	Task	Points	Remarks
Day 1	Task board (20 min × 2 tries)	100	Higher score in 2 tries time bonus (50 points max.) awarded separately
Day 2	Kitting (20 min × 2 tries)	150	Higher score in 2 tries time bonus (50 points max.) awarded separately
Day 3	Assembly w/o surprise (30 min × 2 tries)	100	Higher score in 2 tries time bonus (50 points max.) awarded separately
Day 4	Assembly w/ surprise (60 min × 1 try)	200	Time bonus (100 points max.) awarded separately
Total		550	

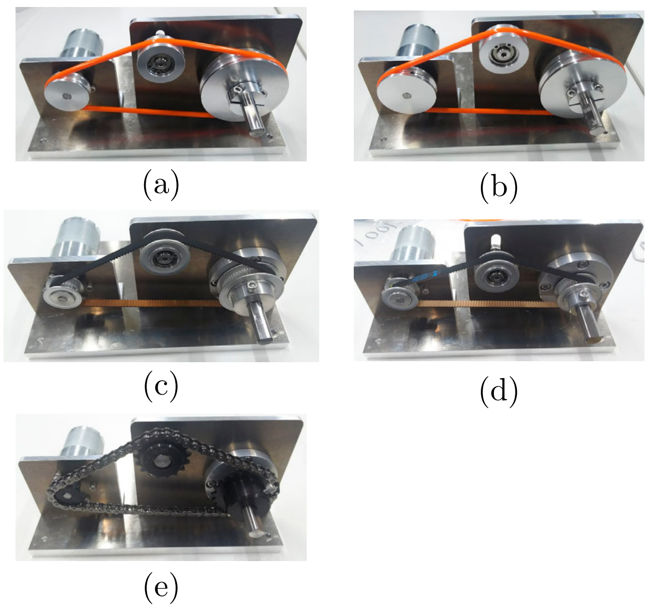


Figure 10. Five types of belt drive units including surprise parts (the numbers in parentheses indicate the graded points of Agility & Leanness according to the degree of difficulty). (a) #0 (10), (b) #1 (15), (c) #2 (50), (d) #3 (55) and (e) #4 (65).

points. This corresponds to completing the three sets in one minute and seven seconds for each set.

In the assembly task, the time bonus is awarded up to 50 points on Day 3, which is equivalent to completing two units in 6 min and 40 s per each unit. On Day 4, it is added up to 100 points, which is equivalent to completing 3 units in 8 minutes and 53 seconds per each unit (one of them has the surprise parts).

As will be described later, none of the teams earned the time bonus granted on the completion of the task in the WRS 2018.

3.6. Safety and health

Safety and health is the most important subject in this competition. Industrial robots and other equipment used in this competition could be a major risk if appropriate safety measures are not taken. Therefore, in the Industrial Robotics Category, we adopted various measures to secure safety and health and obliged the participating teams to comply with safety and health regulations, based on the basic principles of 'safety and health first'.

First of all, based on the complete separation principle, the system running area, where the robot system is running, and the other areas were separated by a safety fence in order to prevent accidents caused by physical contact between the participants or spectators and the articles used for the competition or the scattered objects from those articles. This may be seen as going backwards against the recent trend of removing the safety fence to install collaborative robots. It should be noted, however, that it is only the team area where we can regard as a 'simulated factory' and install collaborative robots. We, therefore, thought that it was necessary to completely separate the team area from the area where general spectators are present in order to ensure intrinsic safety. Also, because the competition rule does not allow human–robot collaboration in the operation phase, there is no problem in completely separating the system running area with the safety fence while the system is running.

We provided the participating teams with safety equipment including a door switch of the safety fence, emergency stop buttons, an indicator light and so on, when they arrived at the competition venue. The participating teams must connect their robot systems properly with those safety equipment when setting up the system at the competition venue. Besides, participating teams must conduct risk assessment of their team areas ('simulated factory') in accordance with ISO10218 series and its upper standards, and submit the results of their risk assessment to the competition committee before the competition. After setting up, the safety inspection is conducted by the Safety and Health Management Committee, and the team must respond to a demand for improvement if any. The participating teams are not able to participate in the competition without passing the safety inspection.

During the competition, the Safety and Health Management Committee conducts safety and health patrols. If they find health and safety concerns, they can recommend corrective actions, stop the competition, advise on compliance with the safety and health regulations, and order the cancellation of participation.

Table 4. Scores and overall standings.

Arena	Team	Day 1	Day 2	Day 3	Day 4	Total	Standings
A-1	Team SAGAMIHARA	6	10	1	1	18	15
A-2	hippopoTaMUs	42	0	1	4	47	9
A-3	Team The Robot System Integrators	50	6	15	24	95	6
A-4	Team.ALGoZa	22	7	3	6	38	11
B-1	JAKS	57	11	22	33	123	2
B-2	Robotic Materials Inc.	62	20	8	15	105	5
B-3	YH-CASIA	0	0	0	11	11	16
B-4	SDU Robotics	92	9	20	24	145	1
C-1	CMIT Robotics	18	1	5	10	34	12
C-2	CPF Robotics	25	3	9	15	52	8
C-3	3up technology	15	4	2	5	26	14
C-4	BerlinAUTs	25	3	11	7	46	10
D-1	FA.COM Robotics	36	8	27	51	122	3
D-2	O2AS	36	13	25	34	108	4
D-3	Cambridge Robotics	6	15	22	44	87	7
D-4	ARTC	16	8	3	5	32	13

4. Results of the competition

4.1. Participating teams

There were 16 participation slots for the Assembly Challenge of the WRS 2018. Since more than 16 teams had applied for this challenge from Japan and other countries, 16 teams, 8 domestic and 8 overseas, were selected by screening based on the submitted application forms. We notified the selected teams in May 2018. The teams in Japan were diverse, including teams from university laboratories, teams collaborating with companies, and teams from system integrators (SIers). Overseas teams come from various regions such as North America, East Asia, Southeast Asia, Europe, and others. Table 4 shows the team names and their assigned arenas, along with their scores and overall standings. The results of the competition will be shown in Section 4.3.

4.2. Robot lending and sample parts

Participating in the Assembly Challenge requires industrial robots or manipulators equivalent to them, meaning that it is costly and not so easy to participate.

Therefore, we have arranged a system for lending two industrial robots (5 kg payload, 700 mm reach) to each requesting team through the WRS-LLP (Limited Liability Partnership) with the cooperation of four robot manufacturers who are also the Global Partners of the WRS 2018. As a result, 6 teams from Japan and 3 overseas teams out of the 16 selected teams requested for this robot lending, and we could lend industrial robots to all these teams.

In the trial competition in 2017, we had sent sample parts to all participating teams in advance for their preparation. Following what we did in 2017, we sent sample parts which are used for the task board, kitting, and assembly tasks to all participating teams in advance.

Like the gear unit used in the trial competition, we made consideration in such a way that most of the parts for the belt drive unit are available from MISUMI Group Inc., which has sales sites around the world, so that the participating teams can easily obtain additional parts. It would also be possible for us to use the tasks of the Assembly Challenge as a benchmark all over the world after the competition.

4.3. Results and discussions

4.3.1. Task board

Since the task board was designed as a collection of elemental tasks extracted from the belt drive unit assembly and teams can try each element individually, the competition committee expected that many teams would get a full score. Actually, however, only SDU Robotics (see Figure 11) got an almost full score and the performance of other teams was not so good. The main reason is that the layout of the task board which was actually used in the competition had been slightly changed from the one previously announced. The drawings of the task board after

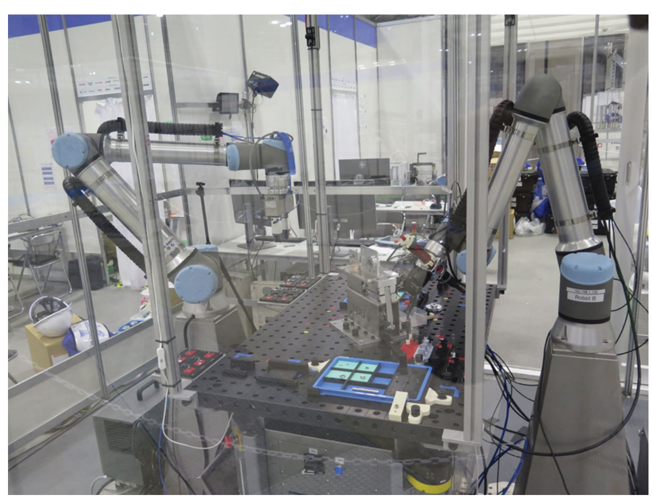
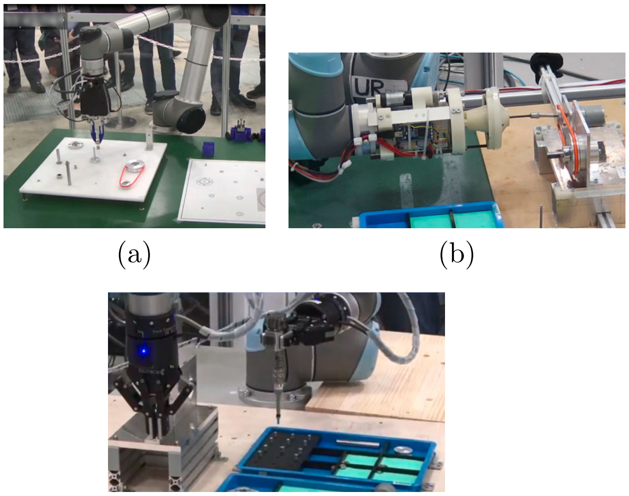


Figure 11. SDU robotics (1st place).



(a) (b) (c)

Figure 12. Examples of remarkable teams other than the top 3 teams. (a) Robotic Materials, Inc., (b) Cambridge robotics and (c) O2AS.

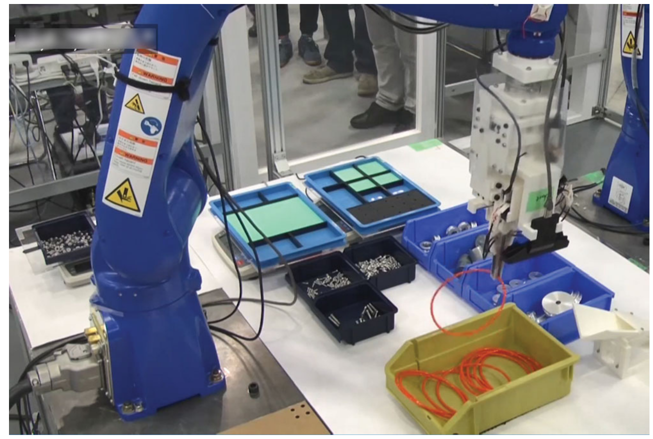
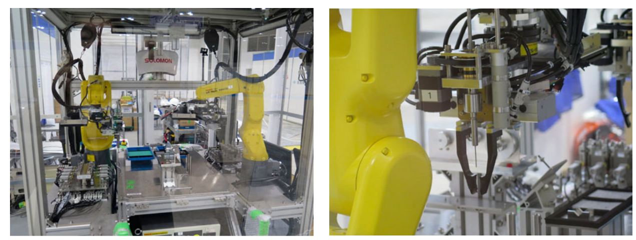


Figure 13. JAKS (2nd place).



(a) (b)

Figure 14. FA.COM Robotics (3rd place). (a) System overview and (b) hand.

the layout change were disclosed to the team on October 15 when the teams started the setup. Actually, the rules stated that there could be a change in the task board layout, but most teams did not expect that the task board layout was changed from the previously announced one, and they could not cope with such a sudden change even knowing it 2 days before. This task board layout change became a surprise in some sense, and how quickly they can respond to this layout change decided their outcome.

SDU Robotics succeeded in assembling all parts except a washer in Try 2 and got the highest score, but missed the time bonus. They introduced a hand that can replace only the fingertips depending on the part to be grasped.

While many other teams introduced multiple arms, Robotic Materials Inc. is impressed by the fact that they used a single two-finger versatile hand attached to a single arm and had achieved high scores by conducting most of the assembly works that can be done with this combination (see Figure 12(a)).

4.3.2. Kitting

Even though the full score was 150 points, the maximum score was just 20 points, and none of the teams could show a good performance in the kitting task.

Many teams seemed to struggle with object recognition, and some teams seemed to have a malfunction problem of the sensors they prepared. In addition, it seemed that some teams had not completely been ready for the kitting task by changing their setup within the limited time from the end of the task-board task in the previous day to the start of the kitting task.

Under such circumstances, it seemed that all teams gave up completing the kitting with the ordered parts sets, rather, they took a strategy to pick only the parts from which they could earn points. It was a disappointing result for those who designed the competition.

Examples of remarkable teams in the kitting task are as follows. JAKS was using a tactile sensor to securely pick only one belt (see Figure 13). Robotic Materials Inc. continued to use a single arm for the kitting task as well and took a strategy to shake the parts bin by the robot if the object recognition was not successful. SDU Robotics scooped and aligned the screws with their custom-made scoop-like end effector. Cambridge Robotics used a strategy to stick and pick up a heteromorphic part, such as the bearing holder, with a clay-like end effector.

4.3.3. Assembly

On Day 3, none of the teams could complete the belt drive unit. They completed only subtasks that they could assemble and carried out the subassemblies to get the score. Even on Day 4, most teams took the same strategy for the first normal unit. Even for the second unit including the surprise parts, many teams ended up without touching the surprise parts at all.

Among them, FA.COM Robotics (see Figure 14) continued assembling patiently while repeating the reset many times, and completed the first unit in 53 min. They also passed the product evaluation test and earned 45 points, the full score for a single unit. After that, they added the points by completing the subtasks of the second unit, and got the highest score on Day 4 as well as on Day 3.

The custom-made hand developed by FA.COM Robotics has a built-in screw driver and can perform screw tightening tasks very smoothly from gripping the screw until fastening it. This two-fingered hand can also grasp various parts without changing the fingers by making multiple notches on the opposite faces of the two fingers (see Figure 14(b)).

It was also impressive that only Cambridge Robotics selected the unit type #4 which includes the most difficult surprise parts (see Figure 10(e)), on Day 4 and they were boldly challenging until the last few seconds. Like the clay-like end effector in the kitting task, they also presented a unique idea of using grease to pick up a screw and prevent the end cap from falling from the output shaft (seeFigure 12(b)). Unfortunately, the fact that grease was attached to the parts was regarded as contamination of parts by the rule, and certain points were deducted.

O2AS, on the other hand, developed a small-sized electric/pneumatic tool that can be held by their robot, so that the robot can approach the target point from various directions by changing the holding posture (see Figure 12(c).).

SDU Robotics was a team who made effective use of the CAD data of the surprise parts disclosed 19 h prior. Using a 3D printer, they manufactured a mock-up of the timing belt pulley, which is one of the surprise parts they chose, as well as a custom-made fingertip for grasping this surprise part. It seems that they had verified whether their custom design fingertip would work well by using the mock-up part before the actual surprise parts were supplied.

4.4. Safety and health

The risk assessment conducted in advance by each participating team was satisfactory in general. However, some teams had the misunderstanding such that 'Safety is secured because we use cooperative robots'.

Safety inspection was conducted after teams had setup their systems. Although some teams needed re-inspection, all the teams had finally passed the inspection. During the competition, unfortunately, there were several important incidents that the Safety and Health Management Committee could not overlook. These include an incident that may violate the complete separation principle and the one resulted from a lack of knowledge about product safety standards.

Although there were some remaining issues regarding safety and health as described above, it was true that the competition was conducted safely by the efforts of the Safety and Health Management Committee. It was also true that the safety awareness of the teams was improved through the competition, according to the team surveys and opinions from the stakeholders.

4.5. Analysis of results

4.5.1. Task board

In this section, we analyze the results of each task in more detail and verify the validity of the competition we designed. Table 5 shows the challenge rate and success rate of each part in Try 2 of the task-board task among 15 teams who participated in this try (one team abstained). The table is arranged in descending order of the success rate. The success rate indicates the rate of teams who achieved the highest completion level for the corresponding part. We can calculate it from the recorded score sheet. The challenge rate means the rate of teams who tried to assemble the corresponding part anyway. The actual challenge rate can be obtained by carefully checking the recorded video, but we approximated it by counting the number of teams who scored some points by achieving some level for the corresponding part, as well as the teams who were deducted some penalty points for this part, which we can see from the score sheet.

From the table, one can see that teams generally selected the parts with low difficulty that can be categorized into peg-in-hole. On the contrary, the success rate of parts requiring screw tightening was generally low. Actually in Try 2, which is analyzed here, only one team, SDU Robotics, tried and succeeded in assembling the M3 bolt and the M6 bolt and nut.

Since the task board was designed to be an extraction of the elements necessary for the assembling the belt drive unit, it is expected that the team with a high score on the task board also has a high score on the assembly. Therefore, we calculated the correlation between the scores of each task in each day. The result is shown in Table 6. Unfortunately, the correlation between the scores of the task board (Day 1) and the scores of the assembly (Days 3 and 4) was low. The only correlation found was between Day 3 and Day 4, but it is obvious because teams performed the same assembly tasks on those days.

There are several possible reasons for the low correlation between the task board and assembly tasks. First of all, we must note that the score of the assembly was generally low. Next, despite of the basic policy of task board design, i.e. extracting the elemental tasks necessary for

Table 5. Analysis of the task-board task result (Try 2).

Part No.	Part name	Points	Challenge rate [%]	Success rate [%]	Type of assembly
4	9 mm Spacer for bearings	5	93.3	80.0	Peg-in-hole
3	17 mm Spacer for bearings	5	86.7	80.0	Peg-in-hole
2	6mm Bearing retainer pin	5	80.0	60.0	Peg-in-hole
10	M10 Washer	6	73.3	60.0	Ring through shaft
14	Pulley	5	66.7	46.7	Ring through shaft
6	4 mm Round belt	10	60.0	46.7	Belt hooking
1	Bearings with housing	5	73.3	40.0	Peg-in-hole
9	M6 Washer	6	60.0	33.3	Ring through shaft
15	M10 End cap	5	53.3	33.3	Fit on shaft
11	M3 Setscrew	10	33.3	26.7	Tightening
8	M12 Nut	8	46.7	20.0	Tightening
13	M4 Bolt	10	26.7	6.7	Tightening
12	M3 Bolt	10	6.7	6.7	Tightening
7	M6 Nut and M6 Bolt	10	6.7	6.7	Tightening

Table 6. Correlations of scores among the tasks.

	Day 1	Day 2	Day 3	Day 4
Day 1	1			
Day 2	0.23	1		
Day 3	0.29	0.37	1	
Day 4	0.20	0.26	0.91	1

Table 7. Success rate of each part in the kitting task.

Part no.	Part name	Rate [%]
10	Bearings spacers for inner ring	28.1
9	End cap for shaft	25.0
12	Bearing spacers for inner ring	19.4
16	M6 Flat Washer	16.3
5	Pulley for round belt – Setscrew, P.D. 30 mm	15.9
15	M6 Hex Nut	15.9
14	Bearing shaft screw	15.0
4	Geared motor	11.9
7	Bearing with housings	11.1
8	Drive shaft	10.0
17	10 mm M4 Socket head cap screw	5.2
18	10 mm M3 Socket head cap screw	2.9
6	Polyurethane round belt	2.1
13	Idler for round belt – Wide	1.7
11	Pulley for round belts – clamping type, P.D. 60 mm	1.6

assembling the belt drive unit, there are some differences in these two tasks, such as the method of supplying parts (the placement mat versus the part-kitting tray) and some parts not used for the belt drive unit (e.g. M12 Nut), etc. The design of the task board will be reviewed for the WRS 2020 competition, considering so as to be more relevant to the assembly.

4.5.2. Kitting

Table 7 shows the success rate of each part through both Tries 1 and 2 of the kiting task. For the appearance of each part, refer to Figure A3 in Appendix. The table is divided into three groups, a group with a relatively high success rate (more than 20%), one with a relatively low rate in 10% range, and one with a very low rate less than 10%.

The parts with a relatively high success rate were moderate in size and easy to be grasped by the robot hand. On the contrary, the parts with a very low success rate include the screws with very small sizes, the flexible belt, and the parts which sizes were large to be grasped by the robot hand, e.g. the pulley with 60 mm in diameter (Part #11). Kitting screw parts was difficult for the teams in two reasons, (i) small and difficult to be recognized and picked up and (ii) it needs to be regrasped for being inserted to the screw holder. Low success rate seems simply because many teams did not even try those parts.

In general, the performance of the team in the kitting task was unsatisfactory, and there is room for reconsideration as the competition task. In particular, although there is a need for bin picking of screws by a robot, screws may be automatically supplied to a special tool even in the actual cell production site. Therefore, in the WRS 2020 competition, we might want to exclude screws from kitting targets and focus only on parts which are difficult to be supplied automatically.

4.5.3. Assembly

Figure 15 shows the total number of subtasks that have been achieved at certain level in the assembly task. Each team had a chance to assemble 7 units in total (2 units × 2 tries on Day 3 and 3 units on Day 4) and the total number of units becomes 112 for 16 teams. However, even the number of the most frequently assembled subtask (Subtask F) was only 39, followed by 35 for Subtask G. These subtasks include a task in which the motor plate and the output shaft plate are screwed onto the base plate, respectively. These two subtasks can be performed at the beginning of the assembly task and are relatively easy because screwing can be performed from the vertical direction. These are the reasons why many teams tried these subtasks.

The next most frequently assembled subtask was Subtask C. However most teams reached only at Level 2, meaning that only the bearing housing was attached to the plate or only the shaft was inserted through the bearing.

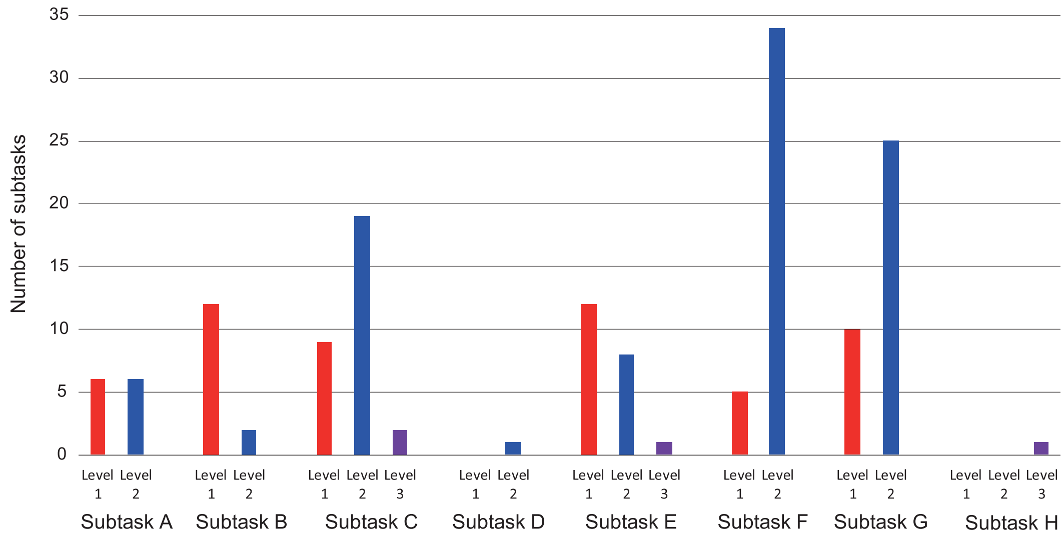


Figure 15. Number of subtasks completed in the assembly task.

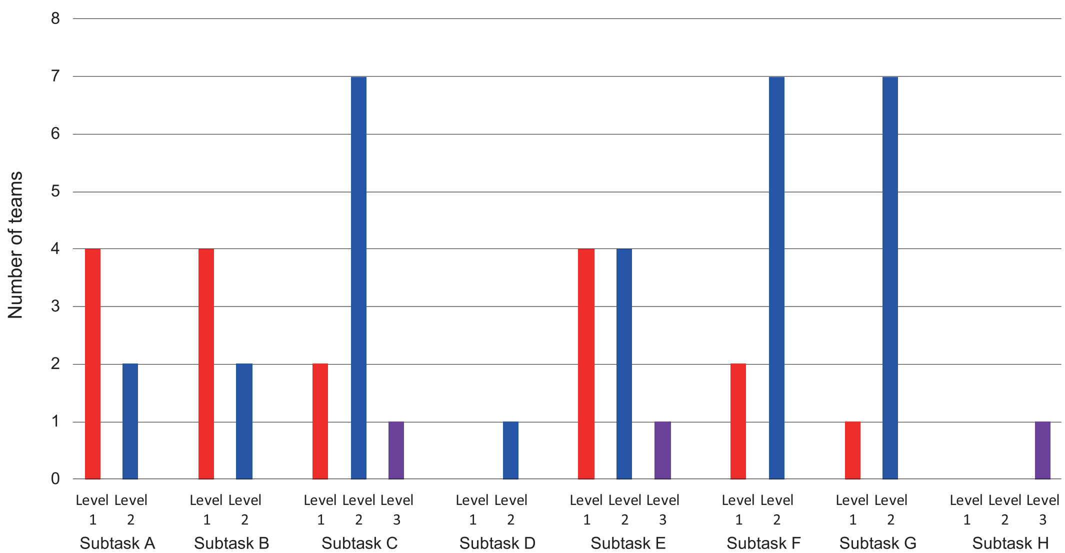


Figure 16. Number of teams who completed each subtask in the assembly task.

Figure 16 shows the number of teams that completed each subtask to a certain level. The number of teams is counted at the highest level achieved even once among seven units in total on Days 3 and 4. From this figure, it becomes clearer which subtask each team tried. One can see that many teams tried Subtasks C and E as well as Subtasks F and G. In Subtask E, however, one can see that the eight teams reached only at Level 1 or 2, meaning that they tried this subtask just for getting partial points as well as in Subtask C.

Regarding the assembly task in the WRS 2018, the performance of the teams was unsatisfactory, and it is obviously due to the lack of preparation of the teams for this task in the limited development period. Therefore, considering the fact that one team had actually completed to assemble the unit, we think that the difficulty level of the assembly task was appropriate.

However, regarding the surprise parts, even if information is disclosed at the competition venue, it would be difficult for the teams to prepare a robot hand that can grasp them. In the WRS 2020, it is possible to disclose the range of the shapes of the surprise parts in advance or request the teams to assemble a new unit, which consists of the parts whose information is already disclosed in advance but is assembled with totally new combination of the parts, as a surprise product.

4.5.4. Agility

Finally, we examined the correlation between the time taken for the preparation phase by the teams immediately after the start of the competition (until the first run of their robots) and the points earned for each task. The reason for this is that the team with a shorter time in the first preparation phase is more likely to have started

Table 8. Correlation between the amount of preparation time and score.

Task (day)	Try	Correlation coefficient	Remark
Taskboard	Try 1	−0.013	None
(Day 1)	Try 2	−0.29	Weak negative
Kitting	Try 1	−0.42	Strong negative
(Day 2)	Try 2	−0.48	Strong negative
Assembly	Try 1	−0.24	Weak negative
(Day 3)	Try 2	−0.17	None
		(−0.51)	(Strong negative if an outlier is excluded.)
Assembly (Day 4)	–	−0.24	None

the robot operation without teaching using the real parts actually provided or physical position adjustments, etc. As a result, it is expected that such a team gets high a score with high agility. Table 8 shows the correlation for each try from Days 1 through 4.

As shown in the table, only Day 2 and Day 3 showed a strong correlation (correlation coefficient of 0.4 or more). The plots for those days are shown in Figure 17. On Day 2, Try 1 and Try 2 showed strong negative correlations of −0.42 and −0.48, respectively. Since the kitting task did not have a surprise factor, one can consider that the team that was well prepared in advance and prepared quickly in the competition took high scores. Therefore, we cannot regard this as the evaluation of agility and leanness for new production demands. On Day 3, although there was a weak negative correlation of −0.25 for Try 1, the correlation coefficient was −0.17 for Try 2 and no correlation was found. However, in the case of Try 2, when the sample at most right end of the plot is excluded as an outlier, a strong negative correlation of −0.51 is recognized. Therefore, it can be considered that the team that was well prepared in advance and prepared quickly in the competition took high scores on Day 3 as well.

In all other cases, no correlation (less than 0.2 correlation coefficient) or just weak negative correlation (less than 0.4) was observed. Try 1 of the task-board task was the first competition in which the board with the new layout was used, and a high correlation should have been obtained from the viewpoint of agility, but no correlation was recognized. A weak negative correlation was observed in Try 2 of the task-board task, and one can interpret that the team who could successfully corrected from Try 1 and shorten the preparation time in Try 2 achieved a high score. Even on Day 4 for assembly with the surprise parts, only a weak negative correlation was observed. It is probably because some teams spent short preparation time but got a low score by taking the strategy for aiming at only partial completion of the subtasks.

Originally, agility should be evaluated by how quickly the team can respond to the surprise parts on Day 4, i.e. the preparation time between the completion of Unit 1 and the start of Unit 2. However, we think that such evaluation has not much meaning in the WRS 2018 because most teams completed Units 1 and 2 only partially.

From the above discussion, we can see that the evaluation of agility is difficult only from the time required for the preparation phase immediately after the start of the competition. Proper evaluation of agility largely depends on how well we design the surprise part/product, and it is an issue for the WRS 2020.

4.6. Summary of Assembly Challenge in WRS 2018

Again, Table 4 shows the points of each task and the total points, and the overall standings. Figure 18 shows the breakdown of the score. Table 9 shows the team that received the Society Award in the Industrial Robotics Category. Overall winner is SDU Robotics. We have an impression that the overall winner is almost decided by the point of the task board.

Many teams struggled to respond to the layout change of the task board disclosed at the competition venue, and

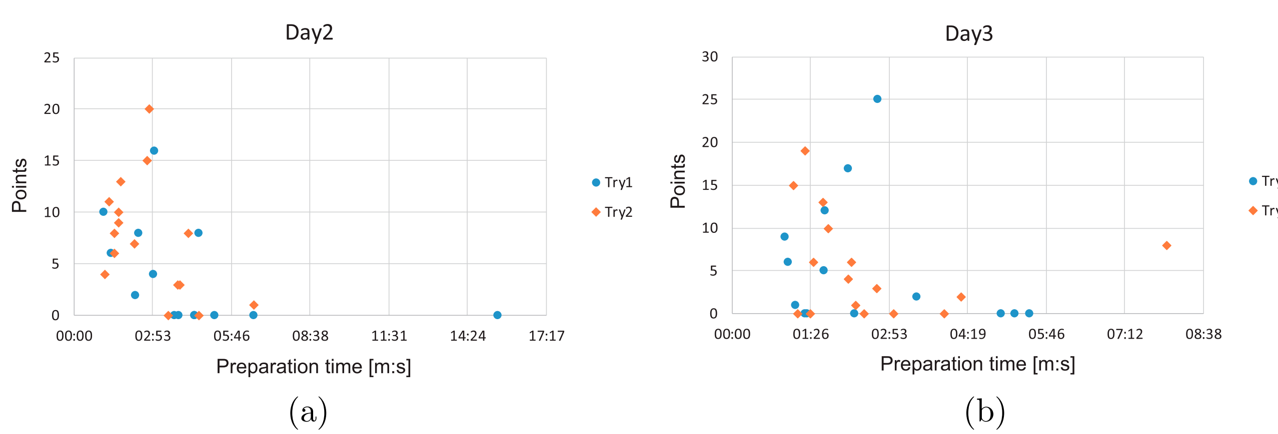


Figure 17. Correlation between the amount of preparation time and score (Days 2 and 3). (a) Day 2 and (b) Day 3.

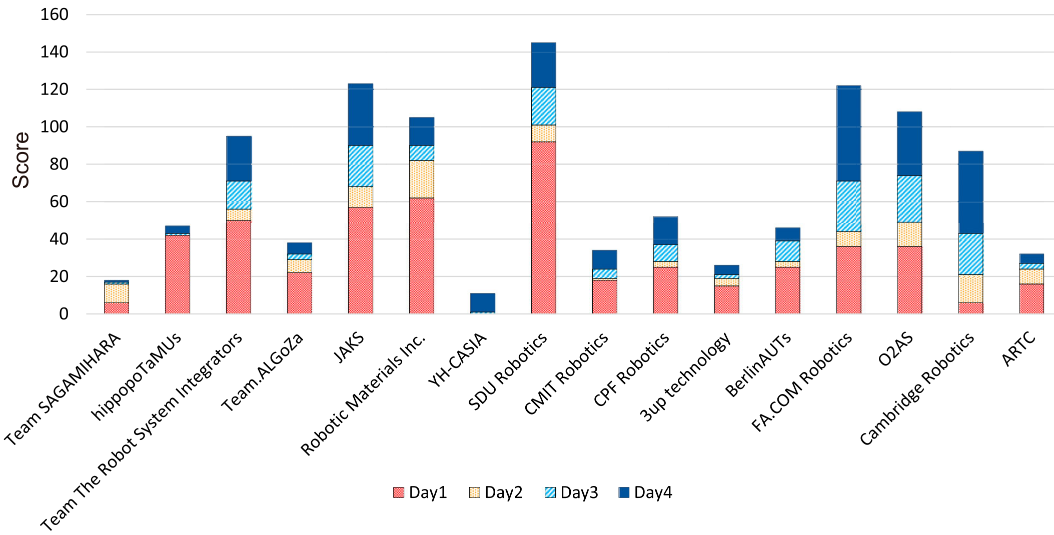


Figure 18. Breakdown of the score.

Table 9. Society award winning teams.

Society	Award	Wining team
The Robotics Society of Japan	RSJ Special Award	Cambridge Robotics
The Japanese Society for Artificial Intelligence	JSAI Award	SDU Robotics
The Japan Society of Mechanical Engineers	JSME President Award	Robotic Materials Inc.
The Society of Instrument and Control Engineers	SICE Award	O2AS

it unintentionally played a role of the surprise parts of this competition. In the kitting task, none of the teams, together with sensor failures, showed a good performance as expected by the competition committee. In the assembly, it was impressive that only FA.COM Robotics completed the belt drive unit on Day 4. However, it should be remembered that it was a normal unit that was completed, and Day 4 was a day when they were expected to deal with the surprise parts.

As mentioned above, the competition of the Industrial Robotics Category, 'Assembly Challenge', of the WRS 2018 successfully ended the five-day period. One may consider that the difficulty level of the competition was too high since even the overall winning team scored less than 30% of the full score. However, all teams who had participated in the competition should have recognized that they did not have enough technical capabilities to complete the tasks imposed at the competition in order to develop the next-generation manufacturing system 'toward agile one-off manufacturing'. In fact, many teams showed their willingness to participate in the WRS 2020 main competition at the post-competition symposium, while realizing the difficulty of the tasks through their experiences of the competition.

Besides, even though we have not mentioned in this paper, even in the teams who did not perform well, the members showed regret tears and cheers with their results. It can be said that this full-scale competition using industrial robots also played a major role in human resource development. Besides, it can be expected that the assembly of the belt drive unit and other tasks together with the results of the competition will be used as a benchmark to evaluate the performance of the robot system developed in each place on the same condition.

In this sense, we could say that the WRS 2018, where we have created a brand new competition, 'Assembly Challenge', was quite successful.

5. Conclusion

In this paper, we introduced the background and history of the competition in the Industrial Robotics Category of the WRS called 'Assembly Challenge', the outline of the competition rules of the WRS 2018 pre-competition, and the results of the pre-competition. Then, we analyzed the results of the competition, and verified the validity of the competition.

Since we are planning to conduct 'Assembly Challenge' again as a competition in the Industrial Robotics Category at the WRS 2020, we would like to give a perspective for the competition in the WRS 2020 here.

The point to be noted in designing a competition in the WRS is that it should be a competition that accelerates the development of the next-generation robot technologies, and must never be a competition for competition. In this sense, we have to reflect on the fact that even in the rules of the Assembly Challenge of the WRS 2018, there were some settings which were hard to assume in the actual production site. Although we need to introduce such unrealistic elements to some extent in order to establish a competition, it is important to remember this point not only for the original purpose of the competition but also for gaining interests and approval from the participating teams.

We would like to discuss some of the issues to be addressed from this viewpoint here. In this competition, we have excluded the element of 'human robot collaboration' that has recently attracted much attention. This is not only the reason for ensuring safety, but also because we, the Industrial Robotics Competition Committee, took the position that the current trend of 'collaborative robots' is merely a 'practical solution' allowing humans to perform tasks that can not be robotized at present and the ultimate goal in the future would be completely automated production. However, through the discussions with overseas researchers especially in Europe, we can notice that they are considering this 'collaboration' issue from different perspectives, such as securing work opportunities for people and adding high value to the products by so-called craftsmanship, which are beyond our view of merely pursuing efficiency.

In addition, the issue of applying IoT/IoS and CPS to the manufacturing domain, such as Industrie 4.0 [26], has not been clearly implemented in the competition of the WRS 2018. Even worse, we reluctantly cut off the network connection of the competition field from the Internet during the competition to prevent fraud such as remote control over the Internet. In a sense, it is a backward step against the concept of 'connected factory'. On the other hand, the fact that SDU Robotics manufactured a custom-made finger for the surprise parts with a 3D printer would be an example of the realization of the CPS concept.

Such technical trends may be introduced naturally by the participating teams without any intention by the competition organizer. Although it may not be feasible to implement as a competition, it would be interesting to design a competition for how quickly the participating teams can respond to new orders by, for example, accepting virtual orders for custom products from spectators through their smartphones, and performing system setup change based on the ordered product data.

Based on the above arguments, we, the Industrial Robotics Competition Committee, will proceed with the competition design for the WRS 2020, while keeping the basic concept of 'Toward agile one-off manufacturing'.

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Notes on contributors

Yasuyoshi Yokokohji received the BS and MS degrees in Precision Engineering in 1984 and 1986, respectively, and PhD degree in Mechanical Engineering in 1991, all from Kyoto University. From 1988 to 1989, he was a research associate in the Automation Research Laboratory, Kyoto University. From 1989 to 1992, he was a research associate in the Division of Applied Systems Science, Faculty of Engineering, Kyoto University. From 1992 to 2005, he was an associate professor in the Department of Mechanical Engineering, Kyoto University. From 2005 to 2009, he was an associate professor in the Department of Mechanical Engineering and Science, Graduate School of Engineering, Kyoto University. From 1994 to 1996, he was a visiting research scholar at the Robotics Institute, Carnegie Mellon University. Since 2009, he has been a professor in the Department of Mechanical Engineering, Graduate School of Engineering, Kobe University. His current research interests are robotics and virtual reality including teleoperation systems, robot hands, and haptic interfaces. He is a fellow of the Robotics Society of Japan, the Japan Society of Mechanical Engineers, and the Society of Instrument and Control Engineers (Japan), and a member of the Institute of Systems, Control and Information Engineers (Japan), the Virtual Reality Society of Japan, and the IEEE (Senior Member). He is a chairperson of the Industrial Robotics Competition Committee, the World Robot Summit.

Yoshihiro Kawai received BE, ME, and Ph.D. degrees in Information Science from Nagoya University, Japan, in 1987. 1989, and 2014, respectively. In 1989, he joined the Electrotechnical Laboratory (ETL), AIST, METI, Japan. He is currently the Director of Intelligent Systems Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan. He is also a Guest Professor at the Tokyo Institute of Technology. His research interests include computer vision and its application, e.g. factory automation systems, humanoid robot systems, assistive systems for the visually disabled person, etc. He has received the best video awards of ICRA'03. He is a member of the Robotics Society of Japan (RSJ), the Information Processing Society of Japan (IPSJ), and the Institute of Electronics, Information, and Communication Engineers (IEICE). He is a vice-chairperson of the Industrial Robotics Competition Committee, the World Robot Summit.

Mizuho Shibata received his Ph.D. degree in Mechanical Engineering from Ritsumeikan University in 2006. He is currently an associate professor at the Department of Robotics, Faculty of Engineering, Kindai University, Japan. His current research interests are the development of applications in soft robotics. He is a member of the Industrial Robotics Competition Committee, the World Robot Summit.

Yasumichi Aiyama received the BS in Precision Machinary Engineering in 1990 and the MS and PhD in Information Engineering in 1992 and 1995 respectively from the University of Tokyo. From 1995 to 1999, he was a research associate in Department of Precision machinary Engineering, the University of Tokyo. From 1999 to 2004, he was a lecturer and from 2004 to 2015, he was an associate professor in University of Tsukuba. He has been a professor in Department of Intelligent Interaction Technologies, Faculty of Engineering, Information and Systems, University of Tsukuba. He is a member of the Robotics Society of Japan (RSJ), the Japan Society of Mechanical Engineers (JSME), the Society of Instrument and Control Engineers (SICE, Japan), the Japan Society for Precision Engineering (JSPE), Japan Association for Automation Advancement (JAAA), Japan Robot Association (JARA) and the IEEE. He is a member of the Industrial Robotics Competition Committee, the World Robot Summit.

Shinya Kotosaka received PhD degree from Saitama University Graduate School of Science and Engineering in 1996. Then, after Encouragement Researcher at RIKEN, Resident researcher at ATR Human Information Communication Research Institute Inc., Researcher at Kawato Dynamics Brain Project by Japan Science and Technology Agency, Currently, Associate Professor of Saitama University. Currently engaged in research on robot safety, adaptive robot motion trajectory generation, industrial robots, and robot human resource development. Member of The Japan Society of Mechanical Engineers, The Society of Measurement Automatic Control, The Robotics Society of Japan (Fellow member). He is a member of the Industrial Robotics Competition Committee, the World Robot Summit, Japan.

Wataru Uemura was born in 1977, and received B.E, M.E. and D.E. degrees from Osaka City University, in 2000, 2002, and 2005. He is an associate professor of the Department of Electronics and Informatics, Faculty of Engineering Science, Ryukoku University in Shiga, Japan. He is a member of IEEE, RoboCup and others.

Akio Noda received the BS and MS degrees in Mechanical Engineering in 1985 and 1987, respectively from Osaka University, and a degree of Doctor of Engineering in 2016 from Nara Institute of Science and Technology. From 1987 to 2016, he had mostly been a researcher at R&D Sections of Mitsubishi Electric Corporation. Since 2017, he has been a professor in the Department of Robotics, Faculty of Robotics and Design, Osaka Institute of Technology. His current research interests are robotics including industrial robot, automated systems and autonomous systems. He received the JRM Best Paper Award 2012, the R&D 100 Award 2014, the FA Fundation Paper Award 2014, the CIE45 Second Award 2015 (Paper Award), the iSCIe Paper Award 2015, the RSJ Paper Award 2016, the iSCIe Industrial Technology Award 2017 (Paper Award), the FA Foundation Paper Award 2017, the RSJ Distinguished Service Award 2018, the SICE Paper Award 2018, and others. He is a fellow of the Robotics Society of Japan (RSJ), a member of the Institute of Systems, Control and Information Engineers (iSCIe, Japan), the Society of Instrument and Control Engineers (SICE, Japan), the Japan Society of Mechanical Engineers (JSME), Japan Robot Association (JARA), and the IEEE, a chair of the Robotics Section of the Institute of Global Safety Promotion. He successively served as a committee member of Ministries and their agencies. He is a member of the Industrial Robotics Competition Committee, the World Robot Summit.

Hiroki Dobashi received the BS, MS, and PhD degrees in Mechanical Engineering from Kyoto University in 2007, 2009, and 2012, respectively. From 2012 to 2013, he was a contract assistant at Kwansei Gakuin University. From 2013 to 2017, he was an assistant professor in the Department of Robotics, Faculty of Science and Engineering, Ritsumeikan University. Since 2017, he has been a lecturer in the Department of Systems Engineering, Faculty of Systems Engineering, Wakayama University. His current research interests are robotic manipulation for manufacturing and logistics. He is a member of the Robotics Society of Japan (RSJ), the Society of Instrument and Control Engineers (SICE, Japan), the Institute of Systems, Control and Information Engineers (ISCIE, Japan), the Japan Society of Mechanical Engineers (JSME), and the IEEE. He is a member of the Industrial Robotics Competition Committee, the World Robot Summit.

Takeshi Sakaguchi received the BS, MS, and PhD degrees in Mechanical Engineering in 1987, 1989, and 1993, respectively, all from Osaka University, Osaka, Japan. In 1993, he joined the Mechanical Engineering Laboratory, MITI, Tsukuba, Japan. From 2001, he was a senior researcher of Intelligent Systems Research Institute (ISRI), the National Institute of Advanced Industrial Science and Technology (AIST). His current research interests are robotics including humanoids, ambient intelligence, and manipulation. He is a member of the Robotics Society of Japan (RSJ), the Japan Society of Mechanical Engineers (JSME), and the Society of Instrument and Control Engineers (SICE, Japan). He is a member of the Industrial Robotics Competition Committee, the World Robot Summit.

Kazuhito Yokoi received the M.E. and Ph.D. degrees in Mechanical Engineering Science from the Tokyo Institute of Technology in 1986 and 1994, respectively. In 1986, he joined the Mechanical Engineering Laboratory, Ministry of International Trade and Industry, Japan. He is currently the Deputy Director General of Department of Department of Information Technology and Human Factors, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan. He is also a Guest Professor of Faculty of Science and Engineering at Waseda University. From April 2005 to July 2015, he was an Adjunctive Professor of the Cooperative Graduate School at the University of Tsukuba. From August 2013 to March 2015, he was a General Manager of the International Research Institute for Nuclear Decommissioning. From November 1994 to October 1995, he was a Visiting Scholar at the Robotics Laboratory, Computer Science Department, Stanford University. He has received the best video awards of ICRA'03 and ICRA'04, the best paper awards of Society of Instrument and Control Engineers (SICE), Robotics Society of Japan (RSJ), and Japan Society of Mechanical Engineers (JSME). He is a Fellow of RSJ and JSME and an AdCom member (2013–2015) of the IEEE Robotics and Automation Society.

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Appendix. Parts information

Table A1. List of parts initially assembled on the task board for the task-board task.

Part no. (Figure 1(a))	MISUMI model no.	Part Name
0	SLON10-30-M6	Hex Posts
5 & 15	SCB4-15, SPWF4, SSFHRW10-75-M4-N4	Bolt & Washer & Rotary Shaft
6_1	MBGNA30-2, TWASS10-6-3	Pulley & Washer
6_2	MBGNA60-2, TWASS14-10-1	Pulley & Washer
7_1	FALBS-AMW-T3-A75-B25-L25-H50-N6-V12-S15-NA4	L Bracket
7_2	SCB4-12, SPWF4	Bolt & Washer
8	SCB12-25, SPWF12	Bolt & Washer
9	SCB6-20, SPWF6	Bolt & Washer
10	MSSFS3-12	Set Screw
11	PSSFAN10-50-F10-B8-P6	Shaft
14	PSSFAN6-50-F10-B8-P4	Shaft

Note: Part #11 is screwed into the main board with 2mm offset.

Table A2. List of parts to be assembled on the task board in the task-board task and allocated points.

			Points			
			Completion Level			
Part no. (Figure 1(b))	MISUMI model no.	Part name	Level 1	Level 2	Level 3	Max.
1	SBARB6200ZZ-30	Bearings with Housing	2	5	–	5
2	BGPSL6-9-L30-F7	6mm Bearing Retainer Pin	2	5	–	5
3	CLBPS10-17-50	17mm Spacer for Bearings	2	5	–	5
4	CLBPS6-9-50	9mm Spacer for Bearings	2	5	–	5
(5)			–	–	–	–
6	MBT4-400	4mm Round Belt	2	6	10	10
7	SLBNR6 & SCB6-10	M6 Nut & Bolt	2	6	10	10
8	SLBNR12	M12 Nut	2	5	8	8
9	SPWF6	6mm Washer	2	6	–	6
10	SPWF10	10mm Washer	2	6	–	6
11	MSSFS3-12	M3 Setscrew	–	6	10	10
12	SCB3-6	M3 Bolt	2	6	10	10
13	SCB4-6	M4 Bolt	2	6	10	10
14	MBRFA30-2-P6	Pulley	2	5	–	5
15	EDCS10	10mm End Cap	2	5	–	5
					Total	100

Notes: Part #5 is already assembled on the main board in the initial condition. This part number remains here to hold the following part numbers.

Table A3. Parts list of the belt drive unit.

Part no. (Figure 4)	MISUMI model no.	Part name	QTY
1	N/A	Base Plate	1
2	N/A	Output Shaft Fixing Plate	1
3	N/A	Motor Fixing Plate	1
4	37D-GEARMOTOR-50-70	Geared Motor (Gear ratio 1:70)	1
5	MBRFA30-2-P6	Pulley for Round Belt (4mm) - Setscrew, P.D. 30mm	1
6	MBT4-400	Polyurethane Round Belt (Welded Joint Product) P.D. 4mm L = 400mm	1
7	SBARB6200ZZ_30	Bearing with Housings (Double Bearings)	1
8	SSFHRT10-75-M4-FC55-G20	Drive Shaft (Straight) D10h7	1
9	EDCS10	End Cap for Shaft	1
10	CLBPS10_17_4	Bearings Spacers for Inner Ring (Output Pulley)	1
11	MBRAC60-2-10	Pulley for Round Belts - Clamping Type, P.D. 60mm	1
12	CLBUS6-9-9.5	Bearing Spacers for Inner Ring (Tension Pulley)	1
13	MBGA30-2	Idler for Round Belt - Wide	1
14	BGPSL6-9-L30-F7	Bearing Shaft Screw	1
15	SLBNR6	M6 Hex Nut (Fixing for Idler Shaft)	1
16	SPWF6	M6 Flat Washer (Fixing for Idler Shaft)	2
17	SCB4-10	10mm M4 Socket Head Cap Screw (Metric Coarse Thread)	9
18	SCB3-10	10mm M3 Socket Head Cap Screw (Metric Coarse Thread)	6
19	MSSFS3-6	6mm M3 Hex Socket Set Screw (Metric Coarse Thread)	1

[NOTE 1] Parts #1-3 are custom-made and not from MISUMI.
[NOTE 2] Part #4 is not a part of MISUMI. It is available from https://www.pololu.com/product/1105.
[NOTE 3] Parts used for kitting are Parts #4-18.

Table A4. Subtasks of the assembly task and allocated points.

Subtask	Description	Completion Level				Max.
		Level 0	Level 1	Level 2	Level 3	
A	Motor to plate with screws	0	2	4	–	4
B	Motor shaft & pulley	0	1	3	–	3
C	Bearing holder & plate, output shaft, washers & screw	0	1	3	5	5
D	Output shaft & pulley	0	1	3	–	3
E	Tension pulley & plate with screw & nut	0	1	3	5	5
F	Motor plate & base plate with screws	0	1	3	–	3
G	Output plate & base plate with screws	0	1	3	–	3
H	Belt with tension	0	1	3	5	5
					Total	31

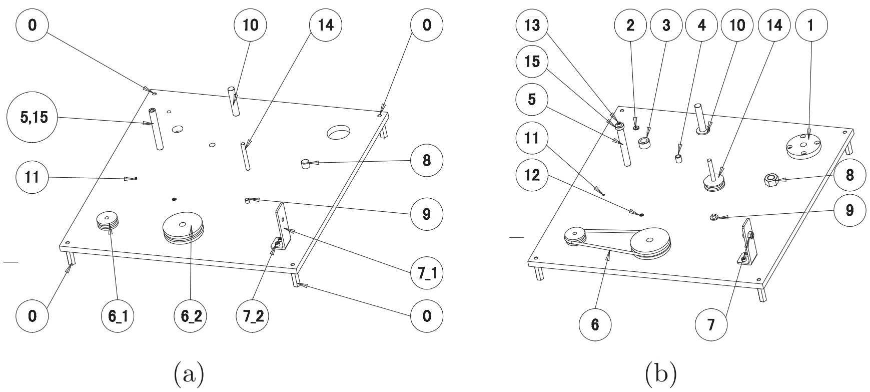

Figure A1. Task board. (a) Initial state and (b) Assembled state.

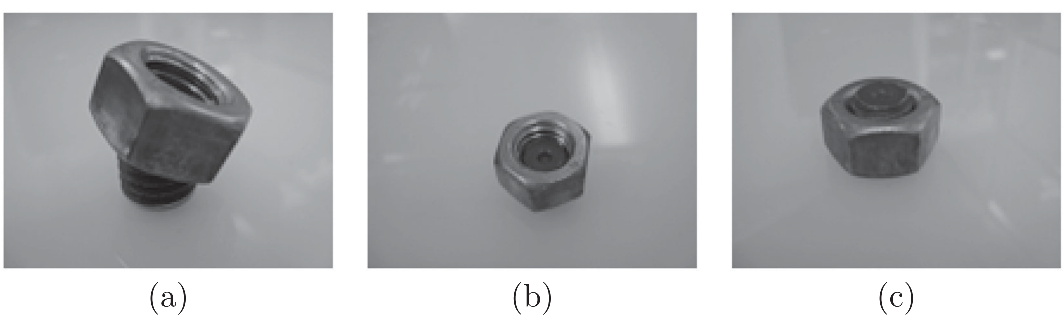

Figure A2. An example of completion level (Part #8); Level 1: Nut stays on bolt, Level 2: Nut tightened partially, Level 3: Nut tightened completely. (a) Level 1, (b) Level 2 and (c) Level 3.

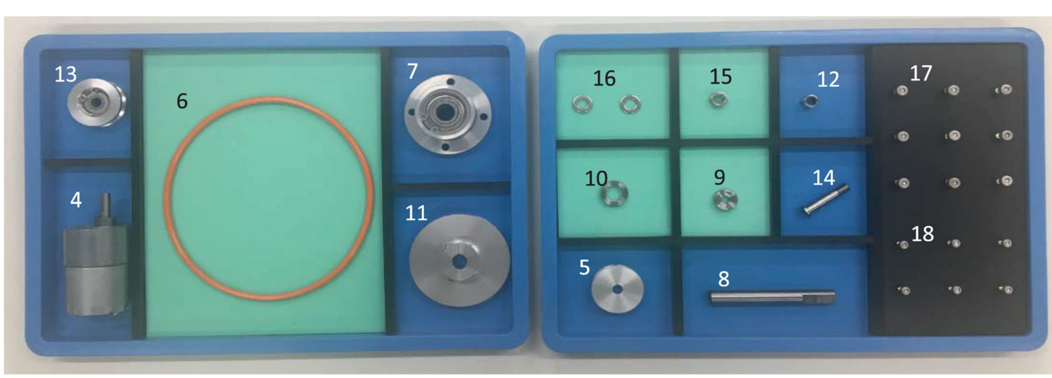

Figure A3. Part-kitting tray with kitted parts with their part numbers.

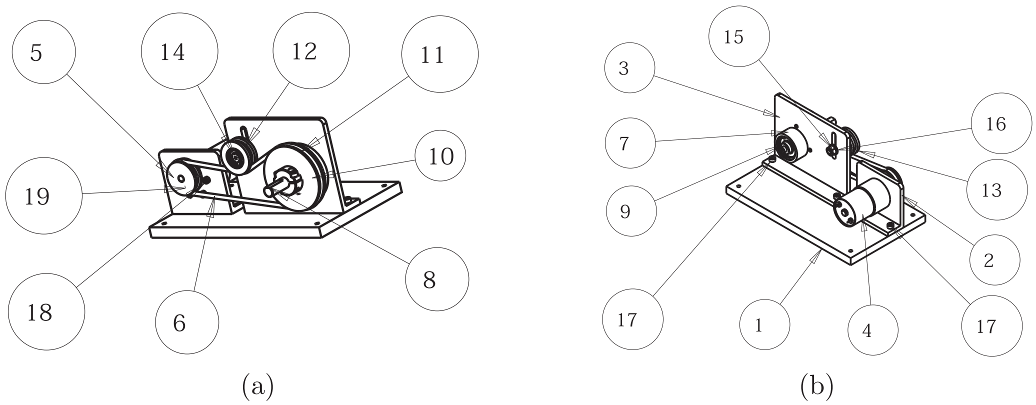

Figure A4. Part numbers of the belt drive unit. (a) Front and (b) Rear.

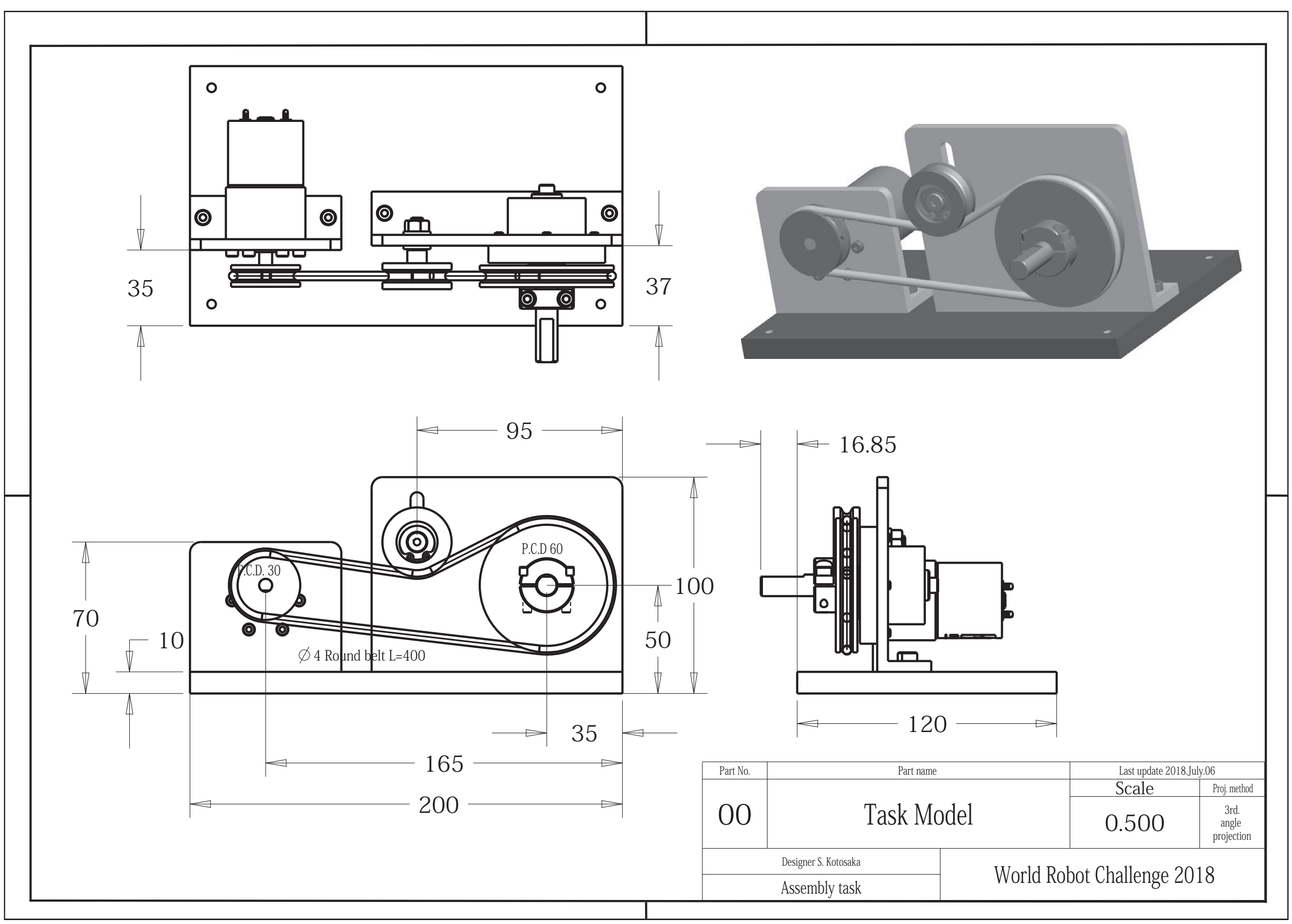

Figure A5. Drawings of the belt drive unit.

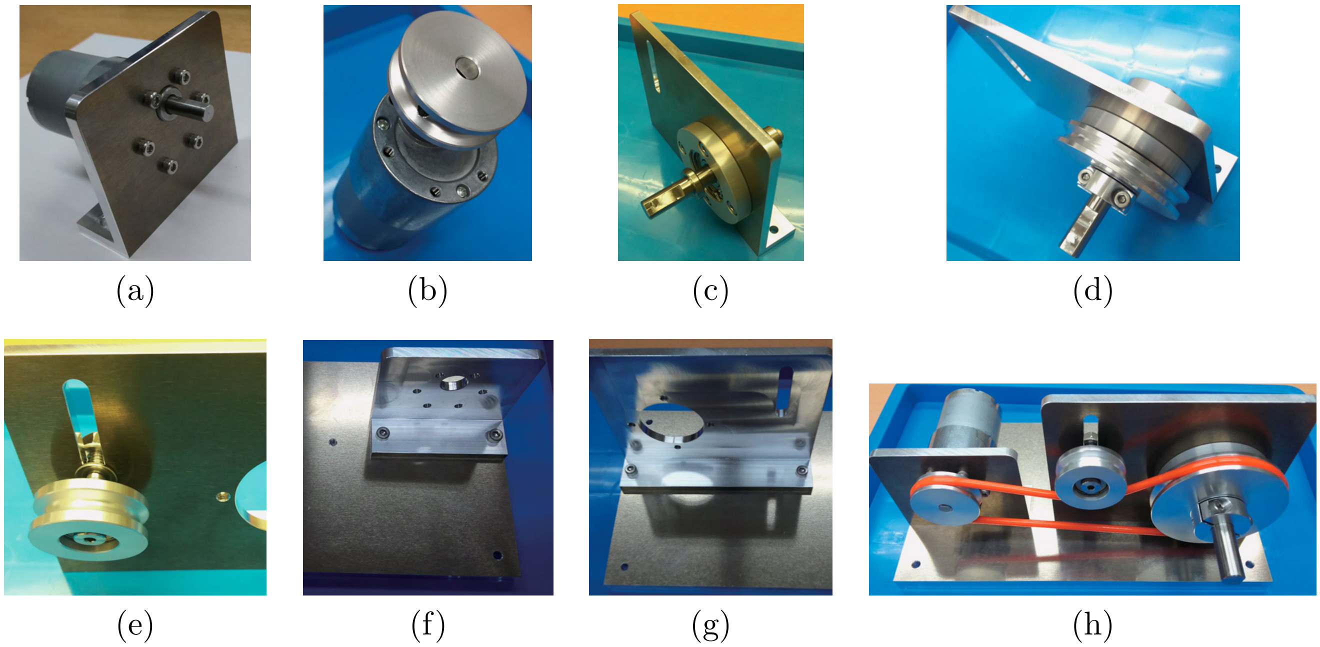

Figure A6. Subtasks of the assembly task. (a) Subtask A, (b) Subtask B, (c) Subtask C, (d) Subtask D (only the difference from Figure A6(c)), (e) Subtask E, (f) Subtask F, (g) Subtask G and (h) Subtask H (only the difference from Figure A6(a)–(g)).

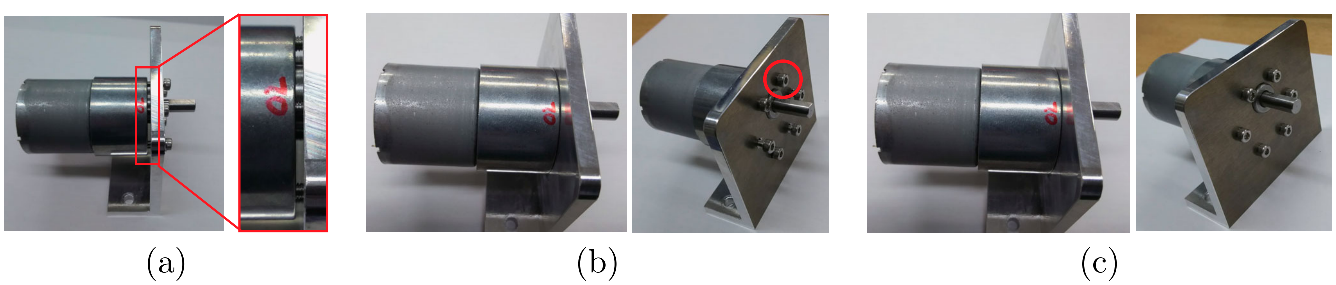

Figure A7. An example of completion level (Subtask A); Level 0: Gap between plate and motor, Level 1: No gap and at least one bolt is completely tightened, Level 2: No gap and all six screws are completely tightened. (a) Level 0, (b) Level 1 and (c) Level 2.