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Task Balancing Between Human and Robot in Mid-Heavy Assembly Tasks

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Abstract

In the manufacturing industry, industrial robots are employed to fulfill the repetitive, well defined and accurate tasks. Regarding the limitation of the robots to perform complex tasks, human intelligence and dexterity are needed to improve the flexibility of the system. The idea of combining the robot repeatability and accuracy with human skill has led to the emergence of Human-Robot Collaboration (HRC) concept. The paper aims to demonstrate that a human-robot workcell may have a capability to increase productivity compared to manual workstations. In this work, we designed and experimented HRC in an assembly of diesel engine components. This paper aims to propose a method for HRC task allocation.

Keywords: Human-Robot Collaboration, Task Allocation, Industrial Robots

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1. Introduction

Over the past decades, the human-robot interaction (HRI) and human-robot collaboration (HRC) have acquired great interests among scholars and on the manufacturing assembly process [1,2]. Traditionally, the assembly process is performed manually by the labor in a repetitive manner. In some of the cases, the poor ergonomic design can result in a long run decrease of a work ability due to physical stress. This leads to health and productivity losses and other associated costs [3]. The industrial robots characteristics such as repeatability, precision, and high payload enabled industries such as automotive to adopt robots in assembly lines. However, the full automation of the assembly tasks is feasible only when the batch sizes are large enough. Currently, the batch sizes are getting smaller thus leading to the need to re-configure the production site more often. The fixed automation is no longer feasible regarding costs and changes over times. Returning to fully manual work may not be an option either, since the demands for higher quality and full traceability have increased in the meantime, therefore demanding flexible automated solutions.

Human characteristics such as cognitive skills, dexterity, and flexibility, and robot's capabilities empowered manufacturing industries to create more flexible assembly cells, provide better ergonomic solutions for operators, and decrease the cost of manufacturing [1]. By expanding the interaction levels in HRC, it might lead to enhancement of the flexibility of shared workspace. For instance, the operator may guide robot by hand and the robot brings power assistance to the operator [3]. With the help of semi-automated assembly workstation, industrial robots can cooperate with the operator as a team to take advantage of their capabilities and characteristics [4]. The combination of the human and robot can be feasible and safe with current practices in most of the cases; however, the increase in production efficiency at the same time with HRC is still hard to achieve.

This paper is divided into seven sections. Section one introduces the topic. Section two represents the related studies, research gap and motivation of study. An approach and methodology will be discussed in section three. The case study in section four discusses the experiment. Results and conclusions will be presented in sections five and six. And

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ultimately, further studies related to the topic of this paper will be presented in section seven.

2. State of the Art

Recently, in the HRC topic, various researches have been conducted on task planning. Chen et al. [5], presented an optimal way for task allocation in assembly. A dual Generalized Stochastic Petri Net (GSPN) model has been studied and proposed assembly strategy based on the time cost and payment cost. Agostini et al. [6], for assisting in the human-robot task planning, proposed a system which integrates AI techniques for planning and learning the capabilities of a robot in the implementation of tasks. Montreuil et al. [7] designed a Human Aware Task Planner (HATP) to handle the constraints of a human-centered system for providing socially acceptable plans which rely on collaborative task achievement. Alili et al. [8] illustrated the HATP abilities to make socially acceptable plans for various agents while considering each agents abilities, preferences and desires related to the HRI.

Kwon and Hong [9] proposed a solution for proactive planning issues with developing the temporal prediction model. With maximization of the temporal utility function, the proactive assistive robot interprets the action which will decrease delays in HRI. Other decision-making frameworks depend on different evaluation criteria has been studied [10], [11,12]; however, the combination of human and robot in the system has not been considered. Galindo et al. [13], focused on semantic map knowledge to depict the beneficial use of this form of knowledge for robot task planning and developing agents more autonomous in HRI cases.

Additionally, Wallhoff et al. [14] presented the hybrid assembly where the operator teaches tasks to the industrial robot simultaneously in shared workspace between robot and operator. Alami et al. [15] developed a decision-making framework for HRI system where the operator was aware of the execution of task sequences. Takata and Hirano [16] proposed a method for hybrid assembly system to minimize the total production cost including robot and labor cost investments.

The trace of human interactions with robots goes back to 1995 [17], this novel topic needs further studies. Recently, human-robot collaboration attracts many scholars. However, there is a lack of literature in the field of industrial HRC and HRI levels. Numerous studies attempt to explore task allocation based on the existing assembly layout. In this paper, the authors try to allocate tasks in industrial human-robot collaboration before the shared workspace layout design and provide a different viewpoint. Furthermore, the authors investigat three distinctive HRI levels in this experiment.

3. Approach

In this research, the assessment methodology (Fig. 1) to allocate task is exploited. This methodology consists of two prime categories: criteria and sub-task. To evaluate and determine the resources (human and robot) for each sub-task, positive and negative assessment is used. The total negative points for each resource is summed up. The resource with less negative points is selected for the sub-task. In the case that negative points for each resource are equal, the task can be allocated to the operator or the robot. Ultimately, a table is generated to demonstrate the task balancing.

The product needs to be disassembled, to explore the components of the assembly process. The assembly stage decomposition model [18] is used to define stages and phases of assembly sequence (Fig. 2). Afterwards, the components at each stage of assembly are assigned as a sub-task for the product. Each sub-task includes one operator or one industrial robot which work aligned together in a shared workspace as resources.

To allocate sub-tasks between the resources an analysis method is employed to provide task balancing. Thus, four criteria's: task complexity, ergonomics, payload, and repeatability are considered to determine and evaluate suitable resource.

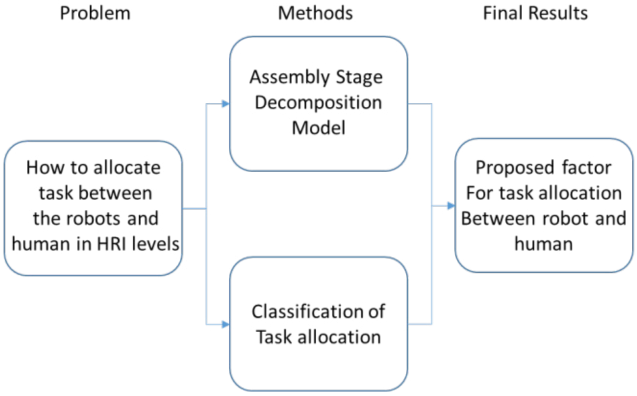

Fig. 1. Approach process.

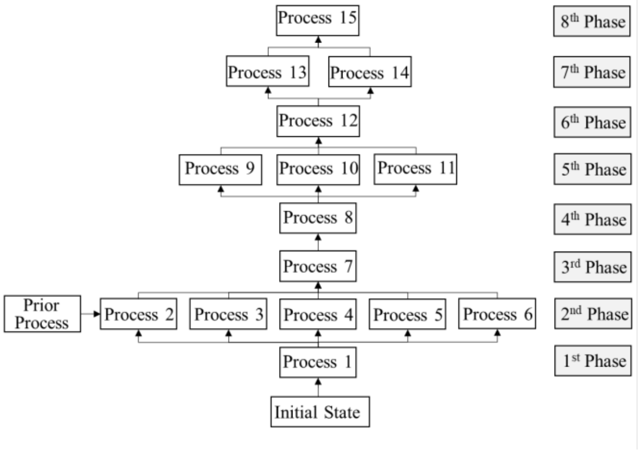

Fig. 2. rearranged diagram of Assembly stage decomposition model [18].

Task complexity is analyzed by considering Samy, S.N. method [19] based on calculation of part complexity. Complexity of each component is calculated in manual and automatic assembly. Manual and automatic assembly consist of handling and insertion attributes. For evaluation of handling attributes in manual and automatic assembly, attributes such as size, thickness, weight, grasping and manipulation, assistance, flexibility, delicateness, stickiness and tangling/nesting are considered. Other elements that are considered in insertion attributes evaluation are holding down, alignment, insertion resistance, mechanical fastening process, non-fastening process and insertion direction. The complexity of each part is calculated regarding the formula (1) [19]:

$$C_{part} = \frac{C_h \sum_1^J C_{h,f} + C_i \sum_1^K C_{i,f}}{\sum_1^J C_{h,f} + \sum_1^K C_{i,f}} \tag{1}$$

Respect to the workstation layout design, two factors such as reachability and insert direction encountered for assessing the ergonomic. Payload criteria is related to the Weight of the components; the heaviness of component is divided to 3 levels. Components under 1 kg are considered as light, more than 1kg and less than 3 kg as mid-heavy and more than 3 kg is heavy. Due to production rate of 80 motors per day, the mid-heavy and heavy components are considered as negative point for human. For robot payload analysis, the payload of gripper is 5kg. Therefore, component over 5kg would get negative point and under 5kg would be positive. Concerning repeatability, task complexity and ergonomics criteria are utilized as factors for evaluation of this criteria.

4. Case study

The proposed method is applied to the HRC workstation for the assembly of selected diesel engine components. The cell resources consist of an ABB IRB 4600 industrial robot with safety controller and a human. The shared workspace is divided into three sections; robot workspace, collaboration workspace and human workspace (Fig. 3). Two zones are defined for the positioning of the human during assembly process. The assembly of the product is implemented in three different interaction levels: shared workspace without shared task, shared workspace and shared task without physical interaction, and shared workspace with shared task "handing-over" based on [20].

In shared workspace without shared task interaction level; human and robot do their own tasks separately, and there is no interference between each other's task by the counterpart resource. Workspace is defined in two zones, one related to the human and one related to the robot. A human can freely move in the human workspace, but if a human wants to enter the robot workspace, the robot shall be stopped. In shared workspace and shared task without physical interaction level; a task is shared between human and robot, but there is no direct contact between them. Furthermore, another zone is added to the workspace as a "cooperate zone" where the robot could assist the human just by holding the part. And finally in shared workspace with shared task "handing-over" interaction level; the shared task between robot and human includes the direct handing-over. For example, the robot picks a component from the assembly line and hands it over human directly [21].

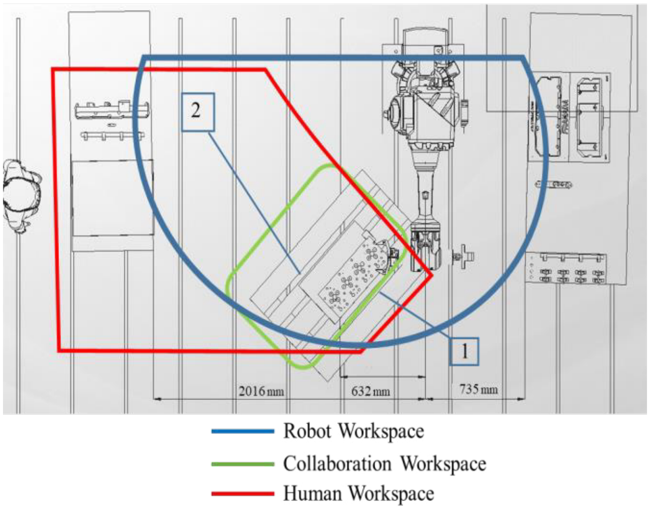

Fig. 3. Workspaces in hybrid assembly.

From disassembly of product and assembly stage decomposition model, a list of assembly components are represented in Table 1, and for each process, a task is determined.

Table 1. Diesel engine components [21].

No	Components	Weight(g)	Amount
1	Exhaust cover of the engine	6170	1
2	Pushrods	100	8
3	Rocker arm	69	8
4	Electric kit and washer	158	1
5	Motor frame	1830	1
6	Screws	16-60	22
7	Nuts	60	3
8	Rocker shaft	4300	1
9	Head cover	1340	1

5. Results

For the first step, task allocation is analyzed based on four factors that described in approach section. For example, respect to evaluation of task complexity, the result of complexity of each part is shown in Table 2. Result of complexity analysis of components

Assembly processes require suitable resources for each task. Based on proposed factors, task balancing for a general hybrid cell is evaluated, and tasks are assigned to the human or the robot (tasks have some modifications regarding definition of different interaction levels, Table 3). In the first and second interaction levels, assembly of rockershaft is assigned to the human. In the third interaction level, picking the motor frame and rockershaft are done by the robot and placing the components is performed by the human.

Table 2. Result of complexity analysis of components.

Part	$C_{p,\text{Manual Assembly}}$	$C_{p,\text{Automatic Assembly}}$
Exhaust Cover	0.78	0.78
Rocker Arm	0.66	0.71
Pushrod	0.66	0.71
Motor Frame	0.65	0.69
Rockershaft	0.80	0.81
Head cover	0.65	0.69
Electric Kit	0.74	0.86

The indication of “Robot & Human” means that task is completed by cooperative operation between resources. The indication of “Robot or Human” means the task can be assigned to a robot or a human.

Table 3. Task allocation of assembly stages between resources [21].

Assembly Process	Task Allocation
Assembly of Exhaust Cover	Robot
Assembly of Rocker Arms	Human
Assembly of Motor Frame	Human or Robot
Assembly of Electric Kit	Human
Assembly of Pushrods	Human or Robot
Assembly of Rockershaft	Human & Robot
Assembly of Head Cover	Human or Robot
Assembly of Bolts and Nuts	Human

Regarding enhancement of resource allocation and improvement of productivity, the time work study has been conducted. The process is repeated for manual assembly and three different interaction levels inside the hybrid cell. In general, the total amount of assembly times is increased by each interaction levels. The total assembly time is mostly determined by the components in high numbers. If these components would be assigned to the robot, it may cause speed limitation of the robot which evidently increases the assembly time rapidly.

Human presence time during whole assembly process is calculated from time work study tables. From Table 4, it can be demonstrated that with proper task allocation between resources, the workload for the human can be decreased which leads to decrease of human fatigue. Additionally, with proper task allocation between resources, it is possible to improve ergonomic for an operator.

Concerning the assembly tasks related to the robot, the automated process time in three HRI levels is studied. This consists of time required to whole assembly of a components or time required for robot to provide component for the operator. According to the result of Table 5 and Table 4, it can be demonstrated that involvement of both resources are nearly equal. As a result, it can be depicted that respect to task allocation in this implementation, the workload for the operator is decreased significantly.

Table 4. The total amount of human working time in different assembly process [21].

Human Assembly Process	Manual Assembly	First Interaction Level	Second Interaction Level	Third Interaction Level
Total Time (s)	418.00	286.88	288.79	275.19

Table 5. The total amount of robot working time in different assembly process [21].

Robot Assembly Process	First Interaction Level	Second Interaction Level	Third Interaction Level
Total Time (s)	217.73	217.73	240.69

In general most of industrial robots don’t have safety functions required for HRC, but such controllers are available. For example, some of ABB industrial robots are utilized by safety features called “SafeMove”, which controls the robot movements according to safety rated monitored stop or speed and separation monitoring requirements [22]. In this implementation, laser scanners is used as safety device to monitor human location. Information is send to the controller of the robot. Afterwards, SafeMove utilizes the scanner signals to stop or limit the speed of the robot in the safe zones which were defined beforehand [23].

6. Conclusions

We have presented a method for justifying the task allocation in HRC in a shared workspace. Based on proposed factors: task complexity, ergonomics, payload, and repeatability, the sub-tasks of the assembly can be assigned to different resources (in this case for a human or robot).

The main outcome of this study demonstrates that with higher HRI levels, there is a possibility to reduce the human active time (in assembly) compared to the manual assembly. Employing HRC enables us to assign heavy assembly tasks to the robot which consequently decrease the operators’ fatigue. Therefore, it leads to less involvement of the operator in the assembly process. Meaning, the additional time of the operator can be used for minor tasks such as feeding components to the robot.

By implementing the developed approach, allocating tasks to humans can be evaluated based on the four criteria in order to ensure the safety, ergonomic and the capability of the labor. According to conducted time work study, productivity did not increase; however, this technique alone may not be adequate to explore productivity.

7. Future work

For future work, a couple of aspects can be investigated. The first one is the development of other factors such as the cost of resources and tools in task allocation. In the current use case, this factor has not been considered because of layout design limitations.

Another aspect is related to justification of task allocation. Simulation of sub-task will determine the time of assembly of each sub-task. The real-time simulation can be implemented. Therefore, multiple scenarios for task allocation can be simulated by the software which leads to choosing the best scenario for the sub-assembly tasks.

Concerning the safety aspect, utilizing the system with more dynamic and real-time monitoring would be considered as future work. Analysis of safety with different interaction levels requires more detailed investigations.

Final aspect will be dedicated to the analysis of the productivity of the operator. Simulation software can provide analysis operator ergonomics and fatigue. This process can be implemented after simulation of primary task allocation to verify sub-task resource allocation. Iteration between resource allocation simulation and analysis of operator performance in workcell may result in finalizing the task allocation before the implementation.

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