

AI supported method to improve the work organization in human-robot-collaboration targeting on semi-autonomous group work

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Abstract

The production environment experiences copious challenges, but likewise discovers many new potential opportunities. To meet the new requirements, caused by the developments towards mass-customization, human-robot-cooperation (HRC) was identified as a key piece of technology and is becoming more and more important. HRC combines the strengths of robots, such as reliability, endurance and repeatability, with the strengths of humans, for instance flexibility and decision-making skills. Notwithstanding the high potential of HRC applications, the technology has not achieved a breakthrough in production so far. Studies have shown that one of the biggest obstacles for implementing HRC is the allocation of tasks. Another key technology that offers various opportunities to improve the production environment is Artificial Intelligence (AI). Therefore, this paper describes an AI supported method to improve the work organization in HRC in regards to the task-allocation. The aim of this method is to build a dynamic, semi-autonomous group work environment which keeps not just employee motivation at a high level, but also the product quality due to a decreased failure rate. The AI helps to detect the perfect condition in which the employee delivers the best performance and also supports at identifying the time when the worker leaves this optimal state. As soon as the employee reaches this trigger event, the allocation of the tasks adapts based on the identified stress. This adaptation aims to return the employee to the state of the optimal performance. In order to realize such a dynamic allocation, this method describes the creation of a pool with various interaction scenarios, as well as the AI supported recognition of the defined trigger event.

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1. Introduction

Evolving markets as well as copious challenges result in new requirements which the production environment faces. Human-robot-cooperation (HRC) was identified as a technology to meet the new requirements in regards to mass-customization and small batch sizes [1]. Although HRC provide a possibility to solve and meet the new requirements the potential is not yet exhausted. [2] identified various burdens for the implementation of HRC. One crucial factor is the acceptance of employees towards HRC. The implementation of HRC is associated with rationalization aspects and results in a resistance towards these technologies. In opposite to this opinion, employees should experience HRC more as colleague and less as a replacement [1]. Besides those aspects the human-robot-interface results in new loads affecting employees. In regards to the raising numbers of musculoskeletal diseases as well as psychological diseases [3] and the demographic change, companies must ensure the performance of their employees [4]. Based on these problems the main goal is to improve the acceptance of HRC and to maintain efficiency by reducing the loads caused by the human-robot-interface. These goals get realized by a situational adjustment of HRC, based on individual stress experienced by the employee [5]. For assessing individual stress various parameter have been considered. Requirements of those parameters are to depict physical loads as well as

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psychological loads. The reduction of the loads is carried out by implementing design approaches defined in DIN EN ISO 10075-2 in the sense of a semi-autonomous group work. The method follows the procedural design approach of Buxbaum [1] for designing HRC. Such a procedural design allows a degree of flexibility in which the method itself can be adjusted. This degree of flexibility offers adjustments that rely on opinions or experiences of the stakeholder. Procedural engineering design is a generally and widely accepted form of engineering design [1]. With regards to the rapidly changing working conditions and new hybrid work systems, learning factories need to sensitize companies and students with regards to occupational science topics. The developed method not only shows the possibility of a human centered approach but also helps trainees and students to understand the possibilities of HRC as well as the functioning of the k-nearest-neighbor algorithm and the aspects of machine learning. By combining AI and hybrid work systems, trainees and students are shown the great optimization potential of AI.

2. State of the art

2.1 Methods for task allocation

Since [2] identified the task allocation as a burden for implementing human-robot-collaboration, there have been various methods worked out, e.g. by [6], [7] and [8]. These methods focus on a task-based approach for allocation. Opposite to the described task allocation methods, [9] proposes a dynamic online re-scheduling method, in which the robot takes over all assembly steps which it is capable of doing in the case of absence of the employee at the workplace.

2.2 Human factors and ergonomics

The integration of semi-autonomous working groups, as a form of work organizations, aims not just to realize economically goals but to achieve human oriented goals such as an increase in productivity [10], performance, motivation, job satisfaction [11], quality of work, creativity, improved humane work design [12], as well as an improved team atmosphere and health-promoting aspects [11, 13, 14]. Semi-autonomous working groups can be described with the following criteria (Table 1):

Table 1. Characteristics of semi-autonomous working group.

Description of criteria	Source
At least two persons	[15]
Joint work order that can be carried out in a jointly manner	[10, 12, 16]
Joint organization of the tasks required to fulfill the order (independent organization of the division and assignment of tasks)	[10, 16]
Jointly negotiated decisions	[10, 16]
Responsibility for the use of resources and work results	[10, 16]
Realization of competence and personality development	[10, 16]

In regards to ergonomic aspects there are various approaches to improve the conditions for employees at their workplace. The key feature method (LMM-MA Leitmerkmalmethode), is an example to assess the loads affecting an employee based on the characteristics of the workplace [17]. Whilst such methods try to prevent employees of misuse of the loads caused by the workplace, the employees still experience stress based on the individual perception [5]. Responsible for the individual stress perception are factors like the individual abilities, age, sex, etc. Due to these individual skills the stress caused by the workplace can lead to consequences of stress [18], even though the loads are limited and evaluated with the LMM-MA. The field of work physiology offers opportunities to track and measure the individual perception of loads with a variety of stress parameter [19]. Heart rate and heart rate variability are two parameter which depict physical loads, trough heart rate and psychological loads, trough heart rate variability [20]. One indicator for a perception of stress is the “continuous duty border”. This border describes a state which an employee is capable to endure over eight hours, without muscular fatigue [21].

2.3 Classification algorithms

Classification algorithms belong to supervised learning methods. Based on training data those algorithms classify data to categorical classes [22]. In this method the k-Nearest Neighbor (k-NN) algorithm is used for individual classification of stress parameter in the classes “overtaxing”, “optimal” and “insufficient”. This algorithm is used because it is a well-known and intuitive algorithm that is similar to a human approach in the way it works [23]. In addition, the algorithm can be applied to large amounts of data and the results can be logically

reproduced [23]. Based on a distance calculation to the k-Nearest Neighbors the data is classified to the class with the highest proximity (probability). Besides the value k, there are more parameter, like the distance metric, that can be adjusted to get the best accuracy [24]. The Euclidean metric measures the distance for $x_i = [x_{i,1}, \dots, x_{i,p}]^T$ and $x_0 = [x_{0,1}, \dots, x_{0,p}]^T$ based on the following formula [25]:

$$d_E(x_i, x_0) = \sqrt{\sum_{j=1}^p (x_{i,j} - x_{0,j})^2} \quad (1)$$

The accuracy of the algorithm parameter can be measured with a x-fold cross validation. This approach divides the data in x parts and uses one part as trainings data and uses the rest data for validation. This procedure is repeated x-times and the result is an average accuracy [23]. Based on the results of the x-fold cross validation of the different algorithms, decision tree (94,7%), naive bayes (94,0%), support vector machine (93,4%), the k-NN algorithm achieved the highest accuracy with 95,4%. For this reason, the k-NN algorithm is used in the described method.

3. Design science research process

This paper follows the process model for design science research of [26]. The model consists of six steps. Considering the first step of the model, the loads at HRC and a future oriented hybrid work system design were identified as problem and the motivation of this paper. Based on that problem the objectives allocation of work tasks based on stress perception and HRC targeting semi-autonomous group work were identified as one solution. In the third step of the process, named as design and development a method for these objectives was defined. With demonstrations like experiments, simulations, case studies, etc. of the developed method, it can be proved to solve one or more instances of the problems. Activity five, the Evaluation, includes the observation and measurement of the performance of the method and the assessment of its support to solve the problems. The last step includes the communication of the developed characteristics. [26]

4. Solution approach

The novelty of this method lies in the combination of adjusting the allocation, based on the employee's individual workload, considering his or her own will. The stated solution is based on the process driven (AI) approach of [27]. This approach identifies AI potential not just based on the given data of the machines, but based on the knowledge of the whole system regarding the environment, process and employee. If necessary, data can be delivered by sensorization. In this solution the individual improvement of ergonomics in an HRC is identified as a potential of AI. The algorithm calculates the perceived individual stress based on the given stress parameter heart rate and heart rate variability.

4.1 Solution overview

The following subsections include the steps necessary for implementing this method. The approach is divided in two steps, the preparation phases and the phases in the value creation process. The preparation phases include all steps that must be realized before it can be used while the production phase. The following phases describe the elaborated steps while the production or assembly process. Fig.1 visualizes the method and its necessary steps.

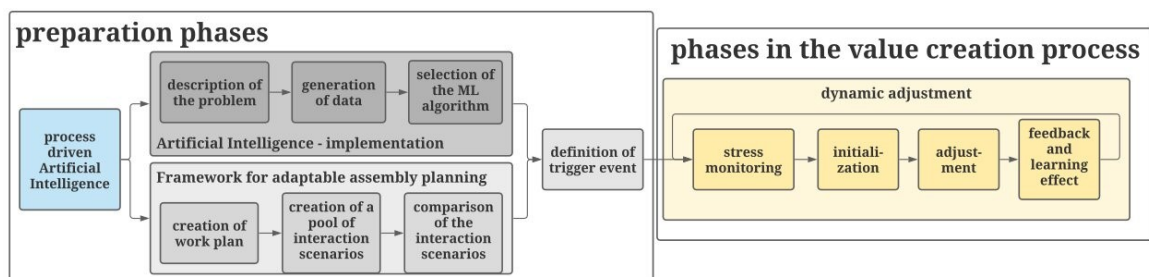


Fig. 1. Method overview.

4.2 Preparation phases

The preparation phases consist of two essential parts. Implementing the AI and building a framework for an adaptable assembly planning. The first one includes all necessary steps to select a machine learning algorithm based on the description of the problem. For this approach the k-NN algorithm is used for the classification

problems. The selection of this algorithm is justified in regards to the high accuracy (95,4%) result of a five-cross validation as well as the possibility for scaling the used stress parameter. The current stress parameter heart rate and heart rate variability can be measured by using a smart watch. The generated data gets classified with the k-NN algorithm in the stress states “overtaxing”, “optimal” and “insufficient”.

The other part describes how a framework for adaptable assembly planning. Based on the work plan, as described by [9], that includes information about precedence relations, task type, resource type and task duration, various interaction alternatives can be defined. Each of those interaction scenarios consists of a defined procedure in which a resource, human or robot, is assigned to the assembly steps. While [9] compares those scenarios based on their utility, the comparison in this approach is focusing on the loads caused by the interaction scenario. This theoretical load is calculated under the premises to consider not just physical but also psychological loads and refers to criteria of [17], [7], DIN EN ISO10075-1:2017. The characteristics of each criteria (K_i) are summed up to calculate the load coefficient for each assembly step (Bk_{Ok}).

$$Bk_{Ok} = \sum_{k=1}^n K_i \quad (2)$$

The load coefficient of an interaction scenario (Bk_{IS}) is based on the load coefficients for each assembly step that is assigned to the employee.

$$Bk_{IS} = \sum_{k=1}^n Bk_{Ok} \quad (3)$$

The interaction scenario with a load coefficient closest to the average load coefficient offers the opportunity to react either to an overtaxing or insufficiency. Therefore, IS 1 is defined as start allocation and offers the opportunity to react to either overtaxing or insufficiency of the employee. The trigger event is the limit that defines when the employee is allowed to adjust the allocation. The definition of this trigger event is a major challenge. The decisive factor is above all the subjective character of stress [18], which makes a general evaluation impossible. For this reason, the stress must be evaluated individually. In addition, a conflict of interests arises between the economic interests of the company and the ergonomic interests of the employee. A compromise is offered by procedural technology design according to [1] in exchange with the employees and with the possibility of adapting the trigger event. This type of technology design was introduced to achieve a certain legitimacy, which is an essential factor for the success of the technology.

4.3 Production phases

The phases during assembly as shown in Fig. 1 includes all necessary steps for implementing a situational adjustment in the value creation process. Based on the fact, that the adjustment is triggered by the individual stress perception, the monitoring of stress parameter is essential. The identified parameter heart rate and heart rate variability are measured with a sport watch. Considering individual conditions these parameters get evaluated by using the k-NN algorithm. In the event of a misuse the employee gets the proposal to adjust the allocation. Depending on the decision whether to adjust the system and the form of misuse, either overtaxing or insufficient, another interaction scenario is selected. In case of overtaxing a scenario with a lower load coefficient is selected and vice versa. Furthermore, the system could learn from evaluating the reaction of the employee based on the adjustment. This information improves further adjustments of the systems. This is an iterative process in order to be able to adapt the work system to evolving situations.

5. Application-Werk150

The approach was implemented in the scooter production of the Werk150. The learning factory Werk150 of the ESB Business School is based on the Campus of Reutlingen University. Werk150 offers an environment for research, development, education and training with various state-of-the-art infrastructure [28]. The product that is assembled in Werk150 is a Micro scooter as shown in Fig. 2 [29].



Fig. 2. Micro Scooter Flex Blue [29].

The red square in Fig. 2 pictures the focused assembly group for which the method was used. The assembly of this group at the designed workplace in Werk150 consists of ten assembly steps, that can be described as pick and place or screwing tasks.

The k-NN algorithm was implemented in MATLAB, because it offers an intuitive environment with a great documentation. Furthermore, it is possible to validate the accuracy of the algorithm as well as converting the code into a high-performance programming language. The necessary training data comprises 150 data sets and is oriented to the continuous power limit. The training data were evaluated on the basis of an individual assessment. The data must be individually adjusted to every employee and therefore offers the opportunity for an individual stress detection. The k-NN algorithm achieved 95.4% accuracy rate with a five-fold cross-validation. Based on this algorithm parameter the actual heart rate and heart rate variability is classified in one of the named classes. Depending on the observation period and the previously defined individual limits of the trigger event, the employee is suggested to adjust the system if this limit is exceeded. Based on the work plan and the load coefficient for each assembly step the possible interaction scenarios can be identified. Table 2 shows the identified scenarios and compares them in regards to cycle time and their theoretical load coefficient.

Table 2. Comparison of interaction scenarios.

Inter-action scenario (IS)	cycle time ISt [min]	load coefficient	allocation
IS 1	3,9	29	start allocation
IS 2	4,54	32	when insufficient
IS 3	4,54	32,25	when insufficient
IS 4	4,17	27,5	when overtaking
average	4,29	30,19	

The calculation of the k-NN algorithm based on the measured stress parameter identified “overtaking” during the period of consideration. In regards to this result the employee has the opportunity to change the interaction scenario to the scenario four due to the smaller load coefficient. The employee decides whether the adaption is made or not. Therefore, he is in charge of the allocation and is not exposed to machine-determined work. This degree of freedom offers the possibility for a self-determined working environment in which the employee can perform the best. The developed method can be implemented in learning factories that possess hybrid work stations with various tasks that can be performed by either human or robot.

6. Validation and Opportunities

Due to the ongoing covid-19 pandemic, on-site validation was not possible in the designated way and manner. Therefore, an expert interview was conducted as a form of content validation with an organizational psychologist with scientific expertise in stress management who confirmed that the hybrid solution presented, in which the employee makes the decision to adapt the system, can be one way to reduce stress in the workplace. The expert also clarified that an objective measurement of stress is difficult to implement due to the subjective nature of stress perception and stress appraisal [18]. The presented hybrid solution provides an opportunity for reducing work-related stress in HRC. Moreover, it offers the possibility of creating synergies with the advantages of semi-autonomous group work. The implementation has revealed new aspects that need to be researched. A potential analysis could be used to select in advance the assembly locations that have the greatest potential for dynamic adaptation. As a rule of thumb, assembly workplaces that involve many steps that can be performed by robots and humans have a higher potential for dynamic adaptation, based on the character of the analysis. Another factor that has an impact on the potential is the type of the task. A change between different task types such as screwing and pick&place can require a change of the end-effector. Therefore, workplaces that include only assembly steps of one type might have a greater potential compared to workplaces where different task types are executed.

7. Conclusion

The described method offers an opportunity for an HRC in the sense of a semi-autonomous groupwork, that can be implemented in learning factories focusing on hybrid assembly, to show trainees or students the possibilities of how HRC can be designed in a human centered approach in the sense of a semi-autonomous group work. The learning factory Werk150 serves as research and application area of the developed method. It also shows an AI based approach to capture individual stress. The k-NN algorithm offers students and companies the opportunity to learn how machine learning algorithms work by using a low-threshold illustrative example. The aspect of individual stress measurement by means of AI was adopted in a graduate's lecture in order to familiarize student with the programming and functioning of machine learning algorithms as well as demonstrate them the potentials of future teamwork between an human and a robot in an collaborative environment. Nevertheless, further research has to be done, especially focusing on work place design because the dynamic character requires a certain degree of flexibility as well as new design requirements. A potential analysis of consisting work place secures on the one hand, that a dynamic adaption can be realized and on the other hand that the greatest potential is released to improve the work conditions for the employees. A collaborative project is being planned to further research semi-autonomous group work in HRC with an additional partner and will be submitted for funding soon.

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