Transdisciplinary Engineering Methods for Social Innovation of Industry 4.0
M. Peruzzini et al. (Eds.)

doi:10.3233/978-1-61499-898-3-239

Inclusion Through Robotics: Designing Human-Robot Collaboration for Handicapped Workers

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Abstract. In the project AQUIAS, a pilot for division of labor in human-robot collaboration was developed, in order to support work quality and healthy working conditions for severely disabled production workers at the valve assembly of ISAK gGmbH. The interdisciplinary research team strived to harmonize the design criteria for the human-robot collaboration development, including technical feasability, safety, ergonomics, work quality, inclusion, and profitability.

Keywords. Human-Robot Collaboration, Inclusion

Introduction

Relevant for the human-machine division of labor in the context of smart technologies is the application field of human-robot collaboration in production [1,2]. The collaboration between robots and humans becoming more and more close, leads to new design challenges for the division of labor [3,4,5,6]. The importance of robots in the German, European and global market is rising considerably [7,8].

Human-robot collaboration is seen as an important key for the scalable automation of assembly, as well as a significant building block for Industry 4.0 [9,10]. A focus in research about assistance and robotic systems is in the area of elderly and patient care in everyday life and in clinical fields of application. However, robotics offer the potential to include limited persons into the production context as well [11]. The job design of hybrid working systems influences the completeness of job tasks, the potential for learning and development of personality, as well as the sustainment of competences [12,13].

In order to prevent a onesided domincance of technology when designing future work processes, solutions for high work quality and healthy working conditions should be developed and applied systematically [14]. This objective can be attained by using alternative scenarios of job task design, which facilitate the variation of division of labor [15,16].

1. Initial Situation

The original workplace (Figure 1) which was chosen to be transferred into a human-robot collaboration workplace in the project AQUIAS, is located in the valve assembly of the inclusion company ISAK gGmbH in Sachsenheim/Stuttgart, Germany. The company occupies about 60 severely disabled workers. In the original work process, a single worker positions two valve elements manually in correct position on a hand lever press. Subsequently, the employee uses the press to join the elements together (Work task 1). In the second step, the joined valves are manually led through a control rack, to verify the size accuracy of the joined valves (Work task 2).

Job task 1
Positioning of the two valve elements manually in correct position and joining the elements together by the hand lever press

Job task 2
Leading the connected valves through a control rack, to verify the size accuracy of the valves

Figure 1. Original workplace at the valve assembly of ISAK gGmbH, which was chosen to be transferred into a human-robot collaboration workplace.

In the following, the main four scenarios of the human-robot collaboration workplace are illustrated together with their dominant characteristics, which evolved in the planning process of the interdisciplinary project team.

2. Results

2.1. First scenario: Human-robot collaboration with high degree of collaboration proximity

Scenario 1 shows a workplace which can be staffed with 1 to 3 workers, collaborating with the robot called Automatic Production Assistant APAS, manufactured by Robert Bosch GmbH (Figure 2). The collaboration distance between human and robot is selected low, in order to foster the spatial and time-based integration of the hybrid job tasks. The valve elements are plugged into two racks with positioning holes, which are arranged in V-shape. If the rack is fit with components completely, the worker presses a button in order to give the robot the signal, that the valves are ready to be put together. After the robot has executed this operation, the worker removes the joined valves from the rack and leads them through the size accuracy control rack, as usually.

Objective of this scenario is not only the low extent of collaboration distance, but also to take advantage of the speed of the robot by assigning 3 workers at a time to it. Besides, this scenario enables handicapped workers with only one functional arm to participate in the work at the human-robot workplace: As the seat neighbour of the worker can take over the rack with his sound arm, which the first worker cannot reach, the second worker can compensate for the performance limit of his or her colleague.

Figure 2. First scenario of the human-robot collaboration workplace for up to 3 workers, designed with V-shaped racks for positioning of the valve elements.

An unfavorable effect of this scenario proved to be, that the robot – caused by the low distance to the worker – is limited to the secured mode to a maximum speed of 0,5 m/second and thus does not reach the affordable speed which would be necessary to serve 3 workers at a time. In this constellation, the workers would have often waiting times, as the robot would reach their racks only with delay. Even more important, in the cardboard-based physical testing of this scenario, the collaboration distance between robot and worker proved to be to low, which would cause acceptance problems on behalf of the workers. Depending on the individual disability, impaired workers can be far more sensitive to fast movements and sudden noises, compared to the average of non-disabled worker.

2.2. Second scenario: Human-robot collaboration with parallel assembly areas for worker and robot on a rotary plate

To manage the challenges described above, the second scenario of the human-robot collaboration workplace offered the following solution (Figure 3). Here, a rotary plate is placed in front of the worker, allowing for the human and the robot each to work parallely on separate, opposite assembly fields on the plate at a time. On each rectangular workpiece carrier, the valve elements are placed manually at positioning pins. By turning the rotary plate for 180 degrees, the worker gives the robot a signal that a further workpiece carrier filled with valves is waiting for the robot to join the valve elements together again.

Figure 3. Second scenario of the human-robot collaboration workplace for up to 3 workers with 2 split assembly fields on the rotary plate. The control rack is arranged in an angle of 90° to the right of the worker.

An disadvantage of scenario 2 can be seen in the fact that the control rack is placed to the right of the worker for spatial reasons, wich makes it necessary for the worker to shift for 90° to the right at the end of each cycle. While this design originally was intended to enable the worker to change his or her body position from time to time, this change of position turned out to be too frequent to be ergonomic, especially for severly disabled workers with rheumatic problems. This would not have been counterbalanced by the positive effect of separating good parts from reject parts at different working areas at the L-form tables.

Although the reduced coupling of the robot and the human work cycles, the robot would neither in this scenario reach the required working speed to serve 3 workers at a time, but would have lowerd the quantity produced by the workers, indirectly. For this reason, in the third scenario, the maximum number of workers allowed was reduced to 2 workers.

2.3. Third scenario:Human-robot collaboration with enlarged degree of spatial and time-related buffer between worker and robot

The third scenario (Figure 4) containes a passive, roll-based conveyor band, arranged between worker and robot. The worker is to place the workpiece carrier filled with valve elements on the conveyor band and let the carrier roll on the central conveyor band towards the robot, driven by the downward slope of the conveyor band, passively. The robot pulls the carrier towards its assembly field, performs the joining process, and after that pushes the carrier to the very right or left conveyor band and lets the carrier roll downwards back to the worker.

Figure 4. Third scenario of the human-robot collaboration workplace for up to 2 workers, with passive roll-based conveyor band.

The length of the conveyer band allows for a higher number of workpiece carriers, thus enabling more spatial buffer and more flexibility between worker and robot in terms of work cycle. The larger distance between robot and human also promised a lower risk for acceptance barriers. However, the manual lifting of the workpiece carriers weighing about 800g each, turned out to be an ergonomic problem. An automatic lifter, which would have raised the workpiece carriers up to the height of the starting point of the passive conveyor band, would made the construction more expensive. The downward slope of the conveyor band also includes the risk that when the carrier touches the end point of the band and stops abruptively, the valve elements could be thrown away from their proper positions on the carrier. Last but not least, the design of the human-robot collaboration workplace based on the conveyor band appeared quite technical to the workers and reduced the physical and mental collaboration proximity between human and robot.

2.4. Fouth scenario:Human-robot collaboration with individual ergonomic support

The fourth scenario of the human-robot collaboration workplace provided for two parallel working tables, whose height can be adjusted independently (Figure 5). At this working place, the robot cooperates with the worker in two ways: First, at the vertical level, the worker can adjust the height of the table anytime – even while in actual operation – along his or her needs, as long as the grappler of the robot stands in the area of the opposite table. Second, the robot supports the worker also at the horizontal level by pulling the workpiece carrier from the handover position on the table towards itself and pushing it back towards the worker, after running the joining operation. In this way, a limitation of the worker's manual range caused by disability, is compensated at least partially.

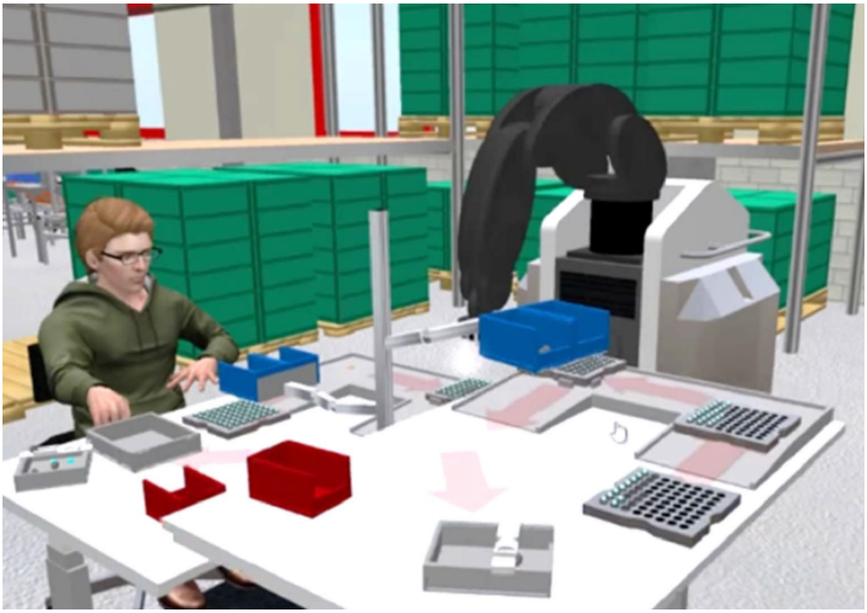

Figure 5. Fourth scenario of the human-robot collaboration workplace for up to 2 workers, with individually height-adjustable tables and flexible arrangement of material and tools by the worker.

The fourth scenario of the human-robot collaboration workplace was chosen for implementation at ISAK gGmbH, as it offers advantages not only in terms of ergonomics. The feeding and other constructional systems were reduced to a minimum, in order to keep costs and complexity of the workplace low. Other than the scenarios 1-3, the worker can arrange working tools, material boxes and gripping tools flexibly and central in its reaching distance, depending on it's personal needs and on the current work task (positioning valve elements vs. checking joined valves).

3. Evaluation

For the evaluation of the working conditions of the human-robot workplace, the assessment tool IMBA (Integration of humans with disabilities into work life) was applied. IMBA is a so-called profile comparison method, as it measures the requirement profile of a given job first and compares it then to the individual ability profile [17]. IMBA covers requirements and abilities which are typical for jobs in sheltered workshops for handicapped workers. Both requirements and ability profiles are operationalized by 70 so-called main characteristics, which are grouped into the following 9 categories:

- Body posture (e.g., sitting/kneeing)
- Body movement (e.g., walking/climbing)
- Movement of body parts (e.g., movement of head/neck)
- Information (e.g., using senses)
- Complex characteristics (e.g., lifting objects)
- Environmental influences (e.g., room climate)
- Requirements on behalf of operational safety (e.g., wearing safety shoes)
- Work organization (e.g., shift working)
- Key qualifications (e.g,, concentration)

By comparing the requirements and ability profiles, the best matching between handicapped workers and given jobs can be determined, as well as over- or underchallenging aspects of a job for a certain worker [18]. If considerable positive or negative deviations between requirements and ability profiles appear, measures for either adapting the job requirements or supporting the worker (e.g., by special tools, ergonomic improvements, or qualification) can be derived from the IMBA results.

In AQUIAS, the IMBA method was not only used to detect requirements vs. ability matchings concerning the newly designed human-robot assembly workplace. Also, the requirements of the original hand lever press assembly job were compared to those of the new hybrid job, in order to detect possible improvements or declines of working conditions caused by automation. The results are shown in Figure 6. Displayed are only deviations between requirements and abilities, which was the case for the indicated 12 items.

The biggest positive deviation comparing the manual and the hybrid assembly job, is shown in terms of "movements of arms". This accords with the robot taking over the most strenuous part of the manual assembly job, that is to say the pressing of the hand lever of the manual press, which originally occurred between 5.000 – 10.000 times a day, depending on the work speed of the worker. Accordingly, in the human-robot work

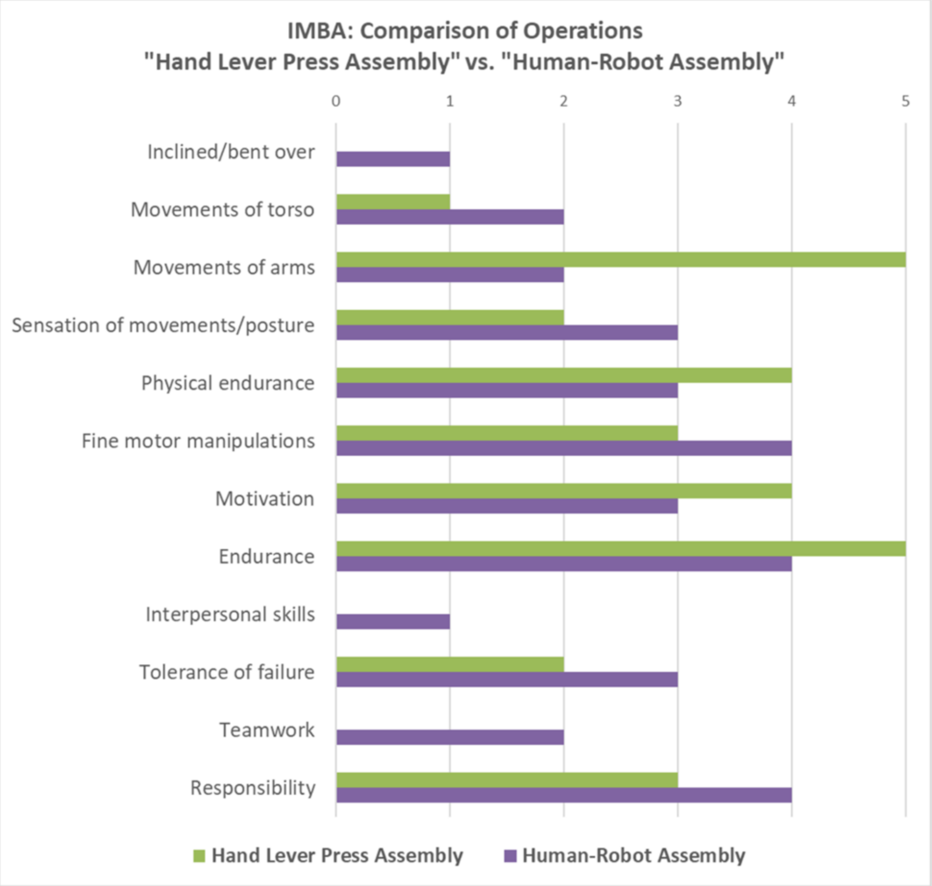

Figure 6. Evaluation results from IMBA (Integration of humans with disabilities into work life) assessment of "Hand lever press" vs. "Human-robot workplace" operations. Only deviations unequal "0" are displayed.

setting, the requirements of physical and mental endurance have decreased. At the soft skill level however, requirements for interpersonal skills and teamwork have risen, as the human-human interaction is supported by the face-to-face workplace design. The same is true for tolerance of failure and responsibility requirements, as workers have to interpret the more complex technical signals and states of the robot, than it was the case with the hand lever press. Also, the risen requirements of sensation and control of body movements indicate that placing the valve base on the workpiece carrier and moving the carrier is demanding not only in terms of fine motor manipulations.

4. Conclusion

The implementation of human-robot collaboration in industry mostly is directed towards objectives of rationalization. Often, the invest for robots is amortized by loss of jobs. However, a win-win situation for workers and companies can be reached when robots take over work tasks which are ergonomically unfavorable. Besides, from the viewpoint of work quality, it is essential that any further work tasks are automatized, especially any of those who contain positive work requirements like learning or cooperation requirements.

The human-robot collaboration pilot which was developed in the AQUIAS project, from the very beginning aimed at designing the work division between worker and robot in a way, that only ergonomically unfavourable work tasks migrated from the worker to the robot. This target was met, as well as the inclusion target of integrating seriously disabled workers: At the human-robot workplace, also persons with *one* handicapped arm/hand can work, whereas at the original manual assembly workplace, workers had to possess *two* healthy arms/hands.

Finally, the learning and information system for the human-robot workplace, which is developped in the further course of the project, will support the handicapped production workers to learn about the work process efficiently and to conduct the quality control, thus preserving the learning and personality developing effect of the job.

The integration of the – often opposed – objectives of work design, inclusion, ergonomics, robot safety, economic and technical feasability demanded a great deal of the interdiscilinary project team of AQUIAS. For the cooperation between work psychologists, a remedial teacher, a business economist, information scientists and engineers within the project team, constantly bridges between the diverse disciplines and working worlds had to be built during the project. The design process, from the different human-robot workplace drafts up to the final workplace design, required endurance from the project partners and an efficient moderation.

References

[1] R. Weidner, N. Kong and J.P. Wulfsberg, Human Hybrid Robot: a new concept for supporting manual assembly tasks, *Production Engineering*, Vol. 7(6) , 2013, pp. 675-684.

[2] G. Echterhoff, G. Bohner and F. Siebler, »Social Robotics« und Mensch-Maschine-Interaktion. Aktuelle Forschung und Relevanz für die Sozialpsychologie, *Zeitschrift für Sozialpsychologie*, Vol. 37(4) , 2006, pp. 219-231.

[3] M.C. Gombolay, R.A. Gutierrez, G.F. Sturla and J.A. Shah, Decision-Making Authority, Team Efficiency and Human Worker Satisfaction in Mixed Human-Robot Teams, In: *Proceedings of the Robots: Science and Systems (RSS)*, 2014.

[4] J.A. Adams, Multiple robot-single human interaction: effects on perceived workload and performance, *Behaviour and Information Technology*, Vol. 28(2), 2009, pp. 183-298.

[5] M. Koppenborg, A. Lungfiel, B. Naber and P. Nickel, Auswirkungen von Autonomie und Geschwindigkeit in der virtuellen Mensch-Roboter-Kollaboration. In: Gesellschaft für Arbeitswissenschaft (Hrsg.) *Chancen durch Arbeits-, Produkt- und Systemgestaltung*, GfA-Press, Dortmund, 2013, pp. 417-420.

[6] A. Bubeck, B. Maidel and F.G. Lopez, Model driven engineering for the implementation of user roles in industrial service robot applications, *Procedia Technology*, Vol. 15, 2014, pp. 605-612.

[7] World Robotics, Executive Summary World Robotics 2017: Industrial Robots, 2017 https://ifr.org/downloads/press/Executive_Summary_WR_2017_Industrial_Robots.pdf Last access at March 22nd 2018.

[8] A. Wendel, Servicerobotik auf dem Vormarsch. In: *VDMA Themen-Supplements, Vol. Servicerobotik - bringt Automation in Schwung*, No. 2014/05, p. 24-25, VDMA Verlag, 5/2014.

[9] VDI, *VDI-Fachkonferenz „Assistenzroboter in der Produktion "*, December 11-12th 2018, Baden-Baden, Germany, 2018. https://www.vdi-wissensforum.de/weiterbildung-automation/assistenzroboter-in-der-produktion/ Last access at March 22nd 2018.

[10] Bundesministerium für Wirtschaft und Technologie BMWi (Hrsg.), *Industrielle Servicerobotik. Technologieprogramm AUTONOMIK*, Band 4, Berlin, 2013.

[11] M.G. Prasch, *Integration leistungsgewandelter Mitarbeiter in die variantenreiche Serienmontage*, Dissertation an der Technischen Universität München, Verlag Herbert Utz, 2010.

[12] T. Weiland, *Arbeitsorganisation und Qualifikation in der Industrie 4.0. Ermittlung der Anforderungen an Management, Mitarbeiter und Arbeitsumfeld in der Produktion*, GRIN Verlag, 2013.

[13] B. Zeller, C. Achtenhagen and S. Föst, Qualifikationsentwicklungen durch das Internet der Dinge in der industriellen Produktion. In: Abicht, L.; Spöttl, G. (Hrsg.) *Qualifikationsentwicklungen durch das Internet der Dinge, FreQueNz-Buchreihe „Qualifikationen erkennen – Berufe gestalten“*; Bd. 15 (hrsg. von H.-J.-Bullinger), Bielefeld, S. 193-267, 2012.

[14] W. Hacker and P. Sachse, *Allgemeine Arbeitspsychologie: Psychische Regulation von Tätigkeiten*, Hogrefe, Göttingen, 2014.

[15] D. Kremer, W. Bauer and S. Hermann, Wie verändern sich Arbeitsaufgaben in zunehmend digital unterstützten Arbeitsprozessen? Ein Ansatz zur Entwicklung von Szenarien für die veränderte Arbeitsteilung zwischen Mensch und intelligenter Produktionstechnik, *61. GfA-Frühjahrskongress 2015 »Verantwortung für die Arbeit der Zukunft« der Gesellschaft für Arbeitswissenschaft*, 25.-27.02.2015, Karlsruhe, Beitrag C.3.12., 2015.

[16] B. Dworschak and H. Zaiser, Competences for Cyber-Physical Systems in Manufacturing – first Findings and Scenarios. In: W. Bauer et al. (Hrsg.): *Disruptive Innovation in Manufacturing Engineering towards the 4th Industrial Revolution: 8th International Conference on Digital Enterprise Technology, DET 2014*, March 25-28 2014, Stuttgart, Germany, *Procedia CIRP*, Vol. 25, 2014, pp. 345-350.

[17] A. Glatz and H.-M. Schian, *IMBA -- Integration für Menschen mit Behinderungen in die Arbeitswelt; in: Diagnostische Verfahren in der Rehabilitation*; Reihe: Diagnostik für Klinik und Praxis, Hogrefe, Göttingen, 2007.

[18] M. Kersting and H. Kaiser, Anforderungen – Fähigkeiten – Profilvergleiche / IMBA als Instrument zur passgenauen Vermittlung von Menschen mit Behinderungen in die Arbeitswelt. In: DRV (Hrsg.): *13. Rehabilitationswissenschaftliches Kolloquium vom 8. bis 10. März 2004 in Düsseldorf*, DRV-Schriften, Bd. 52, 2004, S. 213.