Human-centred assembly and disassembly systems: a survey on technologies, ergonomic, productivity and optimisation

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Abstract: Despite the increasing use of automation in the current industry 4.0 context, manual assembly and disassembly tasks are still common and in some situations even unavoidable. The interaction between humans and other elements of the Assembly and Disassembly Systems (ADS) has been discussed in the scientific literature with the dual objective of optimising human well-being and system performance. Human Factor (HF) related studies focused on new technologies such as motion tracking systems. These technologies enable the collection of data to improve understanding the work environment and its impact on employee well-being and productivity. In the literature, different metrics were suggested to measure the ergonomic and productivity scores. These measurements influence the global system performance and may allow its optimisation. In this paper, we provide a review of the literature on human-centred ADS. We mainly focus on technologies (used to capture human motion), metrics (used to assess human ergonomic risks and productivity), and operational research models (used to optimise the performance system considering economic and cycle time objectives). Future directions are discussed in the perspectives of this paper.

Keywords: Human factor, motion capture, ergonomic and productivity, assembly and disassembly systems, optimisation.

1. INTRODUCTION

In Assembly and Disassembly Environments (ADE), human factor has a crucial role. In these environments, resource configuration, material handling and operator movements must be highly considered so that the manufacturing system is optimised. There is a vast amount of literature on operational research discipline that optimises operations in ADE (Dolgui et al., 2022). Most of the encountered works refer to performance optimisation objectives from a cost and environmental points of view (Guo et al., 2020; Aguilar et al., 2020).

In most of the recent papers (Ozdemir et al., 2021; Battini et al., 2017; Tiacci and Mimmi, 2018), human factor is usually associated with ergonomics. This is encouraged by the global policies to increase focus on workers' wellness and safety. Several ergonomic methods (Gonçalves et al., 2022; Kee, 2022) have been used to compute indicators on posture and motion and then reducing musculoskeletal risks related to assembly and disassembly tasks.

Moreover, we investigate the literature review at the intersection between operational research and HF. Up to 55 works and surveys are reviewed and each layer of assembly workstation design optimisation for better ergonomic and productivity purpose are analysed. We also pointed defined lacks and possible new future directions.

Specifically, the major contributions of this survey regarding the assembly and disassembly environments are as follows: (i) an overview and a comparison of the available technologies used for motion analysis, (ii) the review of most used measurements available to evaluate human ergonomic and productivity with the subtile differences between them, (iii) a taxonomy of existing works that consider the human factor ergonomic in the optimisation process, and finally (iv) an analysis of the status of the works provided in this context and challenging future directions.

The paper is organised as in the following. Section 2 gives a brief overview of the main methods used to measure ergonomic scores and productivity. The third section describes the existing technologies used to record human posture and motion. The forth section looks at the operations research studies which consider performance/HF. Future directions are discussed in the the last section.

2. HUMAN-CENTRED MEASUREMENTS

In the literature, several research works have focused on measuring both operator ergonomic scores and productivity (Joshi and Deshpande, 2019). This has led to the appearance of several methods and measurement scores allowing the evaluation of ergonomics and productivity.

2.1 Ergonomic view point

To sum up, we only review the best known ergonomic methods used in ADE: RULA (Rapid Upper Limb Assessment, McAtamney and Corlett, 1993), REBA (Rapid Entire Body Assessment, Hita-Gutiérrez et al., 2020), OCRA (Occupational Repetitive Action, Tiacci and Mimmi, 2018), QEC (Quick Exposure Check, Fariza and Oktalia, 2021), NIOSH (National Institute for Occupational Safety and Health Otto and Scholl, 2011), EAWS (Ergonomic Assessment Work Sheet, Otto et al., 2019), and OWAS (Ovako Working posture Assessment System, Kee, 2021).

OWAS, RULA and REBA are methods that evaluate the operator working posture through different body parts and the angle of several skeleton joints (Gonçalves et al., 2022). The authors demonstrated that OCRA, RULA, REBA and QEC are the most used ergonomic methods to reduce musculoskeletal risk related to repetitive handling tasks. Besides, most popular methods for assessing ergonomic repetitive tasks are RULA, QEC, and REBA. More detailed differences between these measurements and the manner of their computation can be found in Kee (2022). In addition to indicators computed on posture and motion workers, weight, size, and shape of the components can be considered as factors of ergonomic risks (Ozdemir et al., 2021).

2.2 Productive view point

Productivity measurements on human tasks and their optimisation are important in industry. Here, we are investigating the most relevant measurements by giving examples in some assembly case studies.

In an assembly workstation, Bortolini et al. (2021, 2020, 2018) analysed time and space in order to evaluate working performance of a given operator. To do that, they focus on assembly time, walking time and picking time. Besides, they measure various parameters such as (i) hand displacement and velocity over time and velocity trend, (ii) cumulative vertical movements for lifting and lowering, and (iii) control volume analysis for the distinction between added-value and no added-value activities. Unfortunately, only simple decision has been made and no demonstrated optimisation process on the workstation design is given. Similarly, Ferrari et al. (2018) proposed a Motion Analysis System (MAS) where they study different Key Performance Indicators (KPIs) to measure human productivity in a manual assembly process of a microwave oven. Their system provides time and space analysis of operator activities in a precise workstation area. In Battini et al. (2011), the authors evaluated the productivity by measuring task time and efficiency ratio. In order to consider the evaluation of non-value-adding tasks in assembly lines, Agethen et al. (2016) proposed a novel tracking approach to reconstruct operators' walk paths. Recently, Simonetto et al. (2022) evaluated task execution times by developing various "productivity KPIs".

In the literature reviews of Wang and Abubakar (2017); Di Pasquale et al. (2018), the authors analysed the impact of human factors on productivity performances. More recently, the survey of Abubakar and Wang (2019) founds that experience is the most significant HF which affects individual human performance. However, they highlighted that the least effects are human reaction time and job satisfaction. It is also shown that ageing affects productivity performance: after the age of 38 years old, average assembly time of human workers increases by average 1% per year.

3. MOTION TRACKING SYSTEM TECHNOLOGIES

Tracking systems are the basic technology for the reconstruction of human posture and movements (Maurizio et al., 2019). Recently, to analyse it, industries adopted motion capture (MOCAP) technology whose goal is to record human movements. Menolotto et al. (2020) present a complete review of using MOCAP in industrial applications. Referring to Agethen et al. (2016), we distinguish two groups of this technology: marker-based and markerless motion capture systems. The difference applicability degrees can be found in Ceseracciu et al. (2014).

3.1 Marker-based Motion Capture systems

Inertial Measurement Units (IMUs): In this technology (Ribeiro and Santos, 2017), inertial sensors are miniaturised and placed on the human body parts. Based on an accelerometer, gyroscope and a magnetometer, each inertial measurement provides relative position and orientation updates. IMUs can be installed easily and has fast update rates. Although they have been used for various case studies (Sato and Murata, 2008; Stiefmeier et al., 2008), Bourke et al. (2008) showed that IMUs present several limitations for their application in assembly industrial environment. Besides, one of their main limitations is a lower accuracy of the absolute location of the limbs and the need of wearing inertial sensors by the operator.

Marker-based optical MOCAP: As explained in the review of Colyer et al. (2018), markers are placed on the human body parts. The positions of these markers are detected in 2D thanks to a cluster of calibrated cameras, which enable to triangulate the markers location in 3D space. They are mainly two types of markers: active and passive (Nogueira, 2011). Huge interaction volumes can be tracked with this technology with high accuracy in position and orientation, regarding the number and the pixel resolution of the cameras. It is used in some industrial studies (Thewlis et al., 2013). Nevertheless, this requires to wear a markers suit (as illustrated in the example of Duffy et al. (2007)) which takes 10 to 15 minutes to equip the operator and can sometimes reduce the operator movements due to some occultations and in the calibrated volume only.

3.2 Markerless Motion Capture systems

Pose and position estimations were carried out with camera-based sensors (i.e., RGB, infrared, depth or optical cameras), or in combination with each other Roda-Sanchez et al. (2021). Recently, Desmarais et al. (2021) has reviewed all proposed methods using this technology. Unlike optical markers-based MOCAP that require the operator to wear special suits, optical markerless MOCAP allows the operator to perform his activities in his usual outfit. Two different groups of markerless optical capture technologies can be noticed in literature: **RGB camera-based** systems and **Depth camera**. An example of successful RGB based system is the multi-view MOCAP system by Stoll et al. (2011). Theia industrial system is also really powerfull among markerless system (Kanko et al., 2020). Recently, markerless depth cameras are more and more used in various industrial use cases (see for eg. Bortolini et al., 2018, 2020). They are based on a structured light or time of flight approach and are able to detect specific points of the human body, in order to reconstruct its skeleton. Most popular depth cameras are the Microsoft Kinect V1 and V2 (Wang et al., 2015). V2 is the most recent version that uses time-of-flight technology. This latter is more accurate and enables to capture 25 body joints. It is more robust to artificial illumination and sunlight but still not totally robust to occlusions. An assembly case study that uses Kinect camera is presented in Bortolini et al. (2020); Simonetto et al. (2022).

3.3 Motion Capture in process of productive and ergonomic analysis

As explained by Geiselhart et al. (2016), MOCAP systems are used for different purposes in industry. Our focus in this paper is their use in order to analyse and optimise ADE processes. Besides process optimisations through productive measurements of human tasks, MOCAP enables ergonomic analysis of workplaces. Recently, Simonetto et al. (2022) combined use of Virtual Reality and MOCAP system in assembly case study. This combination consists in creating the virtual environment where the operator equipped with a system will be immersed. It also allows the creation of a digital twin where the operator is represented by his digital copy.

Table 1 summarises the most relevant works in ADE. Capturing technologies, ergonomics and productivity measurements are listed. This points out two capturing techniques are common: markerless optical MOCAP (mainly depth cameras) and inertial measurement units (IMUs). Nearly all listed approaches use a Microsoft Kinect as a depth camera. An evidence from Table 1 is that there is no specific ergonomic score automatically used. Referring to the case study and the nature of the task, the more adapted ergonomic measures are chosen. The MAS proposed by Bortolini et al. (2018) is the most developed for human task productivity measurements. Finally, they are only few researchers that master the whole process from the choice of technology and data collection to the design of the optimised workstation.

Up to 122 works, science 2015, are found using ARTIREV software where used key words are: assembly, ergonomic and productivity (see Fig. 1). This map highlights the current and emerging research themes of the field, with the central authors in each theme: Bortolini et al. (2020), Finco et al. (2020) and Borges et al. (2022).

4. HUMAN-CENTRED OPTIMISATION

Recently, researchers discussed the importance of HF in operating systems (Hashemi-Petroodi et al., 2021). Operational research models address complex optimisation and decision-making issues in several areas of ADS, including strategy production analysis (e.g., Zhu et al., 2018), capacity planning (e.g., Slama et al., 2020) and scheduling issues (e.g., Kim and Xirouchakis, 2010).

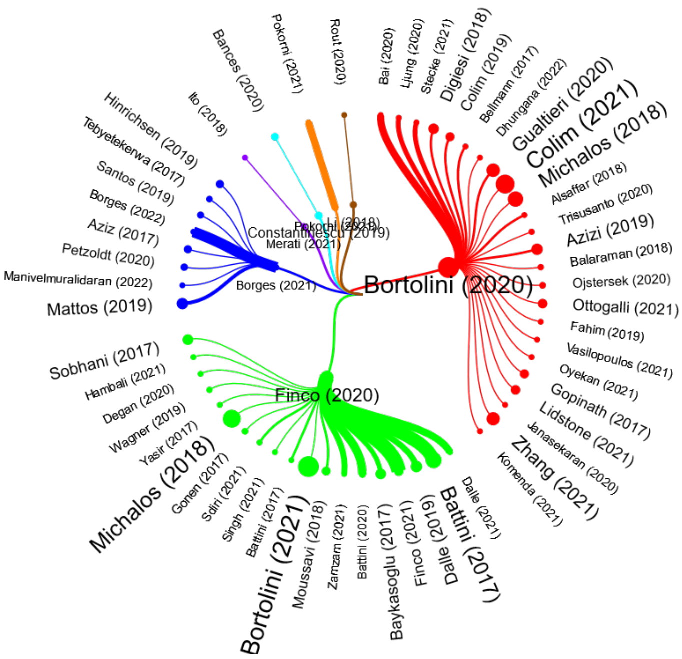

Fig. 1. Research themes with key words: assembly ergonomic productivity.

A review of recent operational research studies shows that they have generally focused on system characteristics such as uncertainty of lead time (e.g., Slama et al., 2021) and technological aspects such as machine failures (e.g., Xia et al., 2018). The majority of these works primarily aimed to optimise economic, environmental and cycle time. These studies rarely considered the effects and causes of work conditions. Typically, they attribute a fixed value to employee performance and don't investigate the risk factors effects on employee capabilities. Therefore, it is important to consider the effects of HF when evaluating system efficiency. The objective is to reduce the cognitive and physical strain of the operator in order to improve ergonomic, productivity, cost and quality.

In this section, we only focus on the integration of HF into ADS optimisation models. This has been recently tackled, and the literature on this subject is still limited (Hashemi-Petroodi et al., 2021).

Based on the recent literature review (since 2015) on ADS human-centred optimisation, the economic and the Cycle Time (CT) performance indicators are the most studied for system-level optimisation. For this reason, Ergo-economic and Ergo-CT studies are the two major research groups briefly reviewed in this section.

4.1 Ergo-economic studies

An optimisation model including the physical effects of work-related ill health risk factors was proposed by Sob-

Table 1. Example of Recent studies analysing human factor in ADE.

Source	Technology	Measurements	
		Ergonomic	Productivity
Nguyen et al. (2015)	DC	EAWS	Working efficiency and time
Agethen et al. (2016)	DC	–	Walk path trajectories
Battini et al. (2017)	–	Energy expenditure	–
Ferrari et al. (2018)	DC	–	Cycle time
Tiacci and Mimmi (2018)	–	OCRA	–
Bortolini et al. (2018)	DC	OWAS, REBA,RULA, IOSH, EAWS	Time and space analysis
Bortolini et al. (2020)	DC	OAWS, REBA, NIOSH, EAWS	Time, motion and space analysis
Finco et al. (2020)	–	Energy expenditure	–
Ozdemir et al. (2021)	–	LBCF, SOJ-W, SOJ-H, RTN	–
Wilhelm et al. (2021)	DC	RULA	–
Bortolini et al. (2021)	DC	REBA	Time, motion and space analysis
Simonetto et al. (2022)	IMU, VR	REBA	KPI
Borges et al. (2022)	IMU	RULA, NASA-TLX	Cycle time

DC: Depth Camera, VR: Virtual Reality, IMU: Inertial Measurement Units

hani et al. (2017). In this paper, the authors suggested a 2-state Markov chain model to quantify the effects of health risk factors and to minimise the total cost of the assembly system. Tiacci and Mimmi (2018) used OCRA index as ergonomic risk to minimise the design cost of assembly lines. Recently, Finco et al. (2021) proposed an optimisation model to minimise the design cost of the whole assembly line integrating ergonomic factors.

4.2 Ergo-CT studies

To reduce system costs, Liu et al. (2021) developed a stochastic multi-product disassembly line balancing problem with workforce allocation. They also use conditional Value-at-Risk (CVaR) constraints to control cycle time. Zhang et al. (2020) investigated the problem of worker allocation and U-shaped assembly balancing using a multi-objective approach to simultaneously minimise ergonomic risks and cycle times. In this paper, the authors proposed a Restarted Iterated Pareto Greedy algorithm to optimise the two objectives. In Wilhelm et al. (2021), human-based optimisation method for assembly line balancing is suggested. In this work, the takt-time is considered as a performance indicator. The proposed algorithm aims to minimise the takt-time of the assembly workstations function and ergonomic RULA-value. In Ozdemir et al. (2021), the authors developed an ergonomic risk assessment based on a fuzzy multi-objective model for assembly line balancing. Considered objectives are minimising: (1) balance of ergonomic risk levels between workers and (2) cycle time.

5. DISCUSSION AND FUTURE DIRECTIONS

In this paper, we provide a review of the literature on human-centred ADS. All existing technologies to capture human movement are revised and discussed. Most relevant ergonomic measurements used in this field are explained and compared. Besides, human productivity measurement are listed and explained. Finally, existing optimisation process are presented and explained. Our work has led us to conclude that most studies are only interested in almost one or two aspects at a time (economic, ergonomics or environmental). The evidence from this study points the idea that several research directions and challenges exist. In the following, we propose some future directions:

- Mastering the whole process from data acquisition to production setup going through ergonomic and productivity measurement and optimisation is a complex task that require multidisciplinary research team with expertise in : computer vision, machine learning, health care, operational research, mathematics modelling and industrial engineering. To the best of our knowledge, in the literature, they are no works that propose a framework where all these layers are taken into account while it is very important and interesting to consider them simultaneously in order to continuously improve each part of the process. In Fig. 2, we proposed the general concept of the complete system that can be applied for both better conception and design of workstation in ADE and economic cost and time of planning. This concept is composed of mainly 3 layers where output of each one is the input of the following. This concept can be seen as an iterative process allowing an auto-improvement progressively and continuously.
- Regarding the appropriate system to record the operator positions, dedicated system to the environmental space should be considered. Optical systems are suffering of occlusions while IMUs can sometimes interfere with electromagnetical systems nearby.
- Almost all optimisation approaches human-centred are given within an assembly case study, very few works give the view point on disassembly systems. An important future direction will be to transpose the studies applied on assembly systems on disassembly case studies. In fact, more and more interest in the community is given to disassembly systems with the sanitary crisis and the relocalisation of manufactories for more and more circular economy.
- The protocol proposed by almost all studies integrating operators is generally not well balanced in term of gender representation. In fact, in these protocols, females are not well represented. Taking in consideration both operator gender and age could be interesting to guarantee an equity between operators. In the future research, the role of the psychological aspect on the human factor deserves to be considered.

REFERENCES

Abubakar, M.I. and Wang, Q. (2019). Key human factors and their effects on human centered assembly perfor-

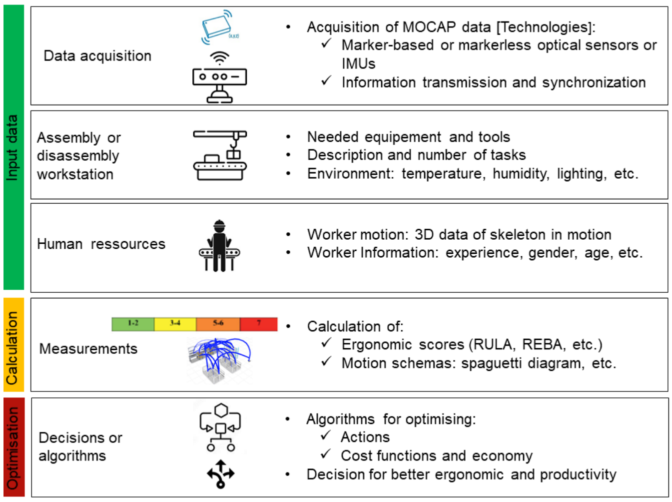

Fig. 2. The proposed concept.

mance. *International Journal of Industrial Ergonomics*, 69, 48–57.

Agethen, P., Otto, M., Mengel, S., and Rukzio, E. (2016). Using marker-less motion capture systems for walk path analysis in paced assembly flow lines. *Procedia Cirp*, 54, 152–157.

Aguilar, H., García-Villoria, A., and Pastor, R. (2020). A survey of the parallel assembly lines balancing problem. *Computers & Operations Research*, 105061.

Battini, D., Faccio, M., Persona, A., and Sgarbossa, F. (2011). New methodological framework to improve productivity and ergonomics in assembly system design. *International Journal of industrial ergonomics*, 41(1), 30–42.

Battini, D., Calzavara, M., Otto, A., and Sgarbossa, F. (2017). Preventing ergonomic risks with integrated planning on assembly line balancing and parts feeding. *International Journal of Production Research*, 55(24), 7452–7472.

Borges, G.D., Mattos, D.L.d., Cardoso, A., Gonçalves, H., Pombeiro, A., Colim, A., Carneiro, P., and Arezes, P.M. (2022). Simulating human-robot collaboration for improving ergonomics and productivity in an assembly workstation: A case study. In *Occupational and Environmental Safety and Health III*, 369–377. Springer.

Bortolini, M., Faccio, M., Galizia, F.G., Gamberi, M., and Pilati, F. (2021). Adaptive automation assembly systems in the industry 4.0 era: a reference framework and full–scale prototype. *Applied Sciences*, 11(3), 1256.

Bortolini, M., Faccio, M., Gamberi, M., and Pilati, F. (2020). Motion analysis system (mas) for production and ergonomics assessment in the manufacturing processes. *Computers & Industrial Engineering*, 139, 105485.

Bortolini, M., Gamberi, M., Pilati, F., and Regattieri, A. (2018). Automatic assessment of the ergonomic risk for manual manufacturing and assembly activities through optical motion capture technology. *Procedia CIRP*, 72, 81–86.

Bourke, A.K., O'Donovan, K.J., and Olaighin, G. (2008). The identification of vertical velocity profiles using an inertial sensor to investigate pre-impact detection of falls. *Medical Engineering & Physics*, 30(7), 937–946.

Ceseracciu, E., Sawacha, Z., and Cobelli, C. (2014). Comparison of markerless and marker-based motion capture technologies through simultaneous data collection during gait: proof of concept. *PloS one*, 9(3), e87640.

Colyer, S.L., Evans, M., Cosker, D.P., and Salo, A.I. (2018). A review of the evolution of vision-based motion analysis and the integration of advanced computer vision methods towards developing a markerless system. *Sports medicine-open*, 4(1), 1–15.

Desmarais, Y., Mottet, D., Slangen, P., and Montesinos, P. (2021). A review of 3d human pose estimation algorithms for markerless motion capture. *Computer Vision and Image Understanding*, 212, 103275.

Di Pasquale, V., Miranda, S., Neumann, W.P., and Setayesh, A. (2018). Human reliability in manual assembly systems: a systematic literature review. *Ifac-Papersonline*, 51(11), 675–680.

Dolgui, A., Sgarbossa, F., and Simonetto, M. (2022). Design and management of assembly systems 4.0: systematic literature review and research agenda. *International Journal of Production Research*, 60(1), 184–210.

Duffy, V.G. et al. (2007). A methodology for assessing industrial workstations using optical motion capture integrated with digital human models. *Occupational Ergonomics*, 7(1), 11–25.

Fariza, R. and Oktalia, R.D. (2021). Cashier work posture analysis using rapid upper limb assessment (RULA) and quick exposure checklist (QEC): A case study in QRS pharmacy. In *International Conference on Science and Engineering*, 163–167. Atlantis Press.

Ferrari, E., Gamberi, M., Pilati, F., and Regattieri, A. (2018). Motion analysis system for the digitalization and assessment of manual manufacturing and assembly processes. *IFAC-PapersOnLine*, 51(11), 411–416.

Finco, S., Abdous, M.A., Calzavara, M., Battini, D., and Delorme, X. (2021). A bi-objective model to include workers' vibration exposure in assembly line design. *IJPR*, 59(13), 4017–4032.

Finco, S., Battini, D., Delorme, X., Persona, A., and Sgarbossa, F. (2020). Workers' rest allowance and smoothing of the workload in assembly lines. *International Journal of Production Research*, 58(4), 1255–1270.

Geiselhart, F., Otto, M., and Rukzio, E. (2016). On the use of multi-depth-camera based motion tracking systems in production planning environments. *Procedia Cirp*, 41, 759–764.

Gonçalves, H., Cardoso, A., Mattos, D., Deola Borges, G., Anacleto, P., Colim, A., Carneiro, P., and Arezes, P.M. (2022). Assessment of work-related musculoskeletal disorders by observational methods in repetitive tasks—a systematic review. *Occupational and Environmental Safety and Health III*, 455–463.

Guo, X., Zhou, M., Abusorrah, A., Alsokhiry, F., and Sedraoui, K. (2020). Disassembly sequence planning: a survey. *IEEE/CAA Journal of Automatica Sinica*, 8(7), 1308–1324.

Hashemi-Petroodi, S.E., Dolgui, A., Kovalev, S., Kovalyov, M.Y., and Thevenin, S. (2021). Workforce reconfiguration strategies in manufacturing systems: a state of the art. *International Journal of Production Research*, 59(22), 6721–6744.

Hita-Gutiérrez, M., Gómez-Galán, M., Díaz-Pérez, M., and Callejón-Ferre, Á.J. (2020). An overview of reba method applications in the world. *International journal of environmental research and public health*, 17(8), 2635.

Joshi, M. and Deshpande, V. (2019). A systematic review of comparative studies on ergonomic assessment techniques. *International Journal of Industrial Ergonomics*, 74, 102865.

Kanko, R., Laende, E., Selbie, S., and Deluzio, K. (2020). Inter-session repeatability of theia3d markerless motion capture gait kinematics. biorxiv 2020.06. 23.155358.

Kee, D. (2021). Comparison of OWAS, RULA and REBA for assessing potential work-related musculoskeletal disorders. *International Journal of Industrial Ergonomics*, 83, 103140.

Kee, D. (2022). Systematic comparison of OWAS, RULA, and REBA based on a literature review. *International Journal of Environmental Research and Public Health*, 19(1), 595.

Kim, H.J. and Xirouchakis, P. (2010). Capacitated disassembly scheduling with random demand. *International Journal of Production Research*, 48(23), 7177–7194.

Liu, X., Chu, F., Zheng, F., Chu, C., and Liu, M. (2021). Distributionally robust and risk-averse optimisation for the stochastic multi-product disassembly line balancing problem with workforce assignment. *International Journal of Production Research*, 1–19.

Maurizio, F., Ferrari, E., Mauro, G., and Pilati, F. (2019). Human factor analyser for work measurement of manual manufacturing and assembly processes. *The International Journal of Advanced Manufacturing Technology*, 103(1-4), 861–877.

McAtamney, L. and Corlett, E.N. (1993). Rula: a survey method for the investigation of work-related upper limb disorders. *Applied ergonomics*, 24(2), 91–99.

Menolotto, M., Komaris, D.S., Tedesco, S., O'Flynn, B., and Walsh, M. (2020). Motion capture technology in industrial applications: A systematic review. *Sensors*, 20(19), 5687.

Nguyen, T.D., McFarland, R., Kleinsorge, M., Krüger, J., and Seliger, G. (2015). Adaptive qualification and assistance modules for manual assembly workplaces. *Procedia CIRP*, 26, 115–120.

Nogueira, P. (2011). Motion capture fundamentals. In *Doctoral Symposium in Informatics Engineering*, 303.

Otto, A. and Scholl, A. (2011). Incorporating ergonomic risks into assembly line balancing. *European Journal of Operational Research*, 212(2), 277–286.

Otto, M., Lampen, E., Auris, F., Gaisbauer, F., and Rukzio, E. (2019). Applicability evaluation of kinect for eaws ergonomic assessments. *Proc. CIRP*, 81, 781–784.

Ozdemir, R., Sarigol, I., AlMutairi, S., AlMeea, S., Murad, A., Naqi, A., and AlNasser, N. (2021). Fuzzy multi-objective model for assembly line balancing with ergonomic risks consideration. *International Journal of Production Economics*, 108188.

Ribeiro, N.F. and Santos, C.P. (2017). Inertial measurement units: A brief state of the art on gait analysis. In *5th Portuguese Meeting on Bioengineering*, 1–4.

Roda-Sanchez, L., Garrido-Hidalgo, C., García, A.S., Olivares, T., and Fernández-Caballero, A. (2021). Comparison of rgb-d and imu-based gesture recognition for human-robot interaction in remanufacturing. *The International Journal of Advanced Manufacturing Technology*, 1–13.

Sato, N. and Murata, Y. (2008). Quality control schemes for industrial production by workers' motion capture. In *22nd International Conference on Advanced Information Networking and Applications-Workshops (aina workshops 2008)*, 1480–1485. IEEE.

Simonetto, M., Arena, S., and Peron, M. (2022). A methodological framework to integrate motion capture system and virtual reality for assembly system 4.0 workplace design. *Safety Science*, 146, 105561.

Slama, I., Ben-Ammar, O., Dolgui, A., and Masmoudi, F. (2020). New mixed integer approach to solve a multi-level capacitated disassembly lot-sizing problem with defective items and backlogging. *Journal of Manufacturing Systems*, 56, 50–57.

Slama, I., Ben-Ammar, O., Dolgui, A., and Masmoudi, F. (2021). Genetic algorithm and monte carlo simulation for a stochastic capacitated disassembly lot-sizing problem under random lead times. *Computers & Industrial Engineering*, 107468.

Sobhani, A., Wahab, M., and Neumann, W. (2017). Incorporating human factors-related performance variation in optimizing a serial system. *EJOR*, 257(1), 69–83.

Stiefmeier, T., Roggen, D., Ogris, G., Lukowicz, P., and Tröster, G. (2008). Wearable activity tracking in car manufacturing. *IEEE Perv. Computing*, 7(2), 42–50.

Stoll, C., Hasler, N., Gall, J., Seidel, H.P., and Theobalt, C. (2011). Fast articulated motion tracking using a sums of gaussians body model. In *2011 International Conference on Computer Vision*, 951–958. IEEE.

Thewlis, D., Bishop, C., Daniell, N., and Paul, G. (2013). Next-generation low-cost motion capture systems can provide comparable spatial accuracy to high-end systems. *Journal of applied biomechanics*, 29(1), 112–117.

Tiacci, L. and Mimmi, M. (2018). Integrating ergonomic risks evaluation through ocra index and balancing/sequencing decisions for mixed model stochastic asynchronous assembly lines. *Omega*, 78, 112–138.

Wang, Q. and Abubakar, M.I. (2017). Human factors and their effects on human-centred assembly systems–a literature review-based study. In *IOP Conference Series: Materials Science and Engineering*, volume 239.

Wang, Q., Kurillo, G., Ofli, F., and Bajcsy, R. (2015). Evaluation of pose tracking accuracy in the first and second generations of microsoft kinect. In *2015 international conference on healthcare informatics*, 380–389.

Wilhelm, M., Manghisi, V.M., Uva, A., Fiorentino, M., Bräutigam, V., Engelmann, B., and Schmitt, J. (2021). Ergotakt: A novel approach of human-centered balancing of manual assembly lines. *Proc. CIRP*, 97, 354–360.

Xia, T., Dong, Y., Xiao, L., Du, S., Pan, E., and Xi, L. (2018). Recent advances in prognostics and health management for advanced manufacturing paradigms. *Reliability Engineering & System Safety*, 178, 255–268.

Zhang, Z., Tang, Q., Ruiz, R., and Zhang, L. (2020). Ergonomic risk and cycle time minimization for the u-shaped worker assignment assembly line balancing problem: A multi-objective approach. *Computers & Operations Research*, 118, 104905.

Zhu, Q., Shah, P., and Sarkis, J. (2018). Addition by subtraction: Integrating product deletion with lean and sustainable supply chain management. *IJPE*, 205, 201–214.