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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 subtle 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 fourth 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 \(2019\)](#) finds 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

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.

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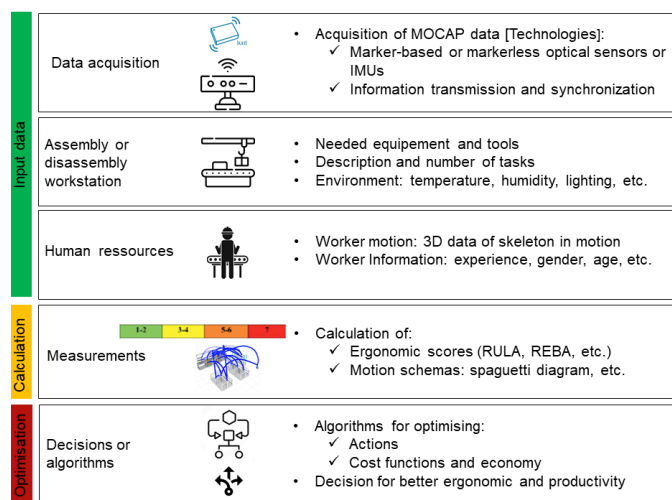


Fig. 2. The proposed concept.

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