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Creating a Worker-Individual Physical Ability Profile Using a Low-Cost Depth Camera

Justus Brosche[1], Hannes Wackerle[2], Hermann Lödding[1]

[1]*Institute of Production Management & Technology, Hamburg University of Technology, Hamburg, Germany*
[2]*Institute for Biomechanics, BG Unfallklinik Murnau, Murnau, Germany and Paracelsus Medical University Salzburg, Salzburg, Austria*

Abstract

Assembly workers suffer from long-term damage performing physically intensive tasks due to workstations that are not ergonomically designed for the individual's needs. Current approaches towards ergonomic improvements of workstations only assess the workstations themselves without taking the individual worker and abilities into account. Therefore, physical limitations, such as age-related loss of range of motion, are not addressed. Work-induced long-term damages result in employee absences, especially of workers close to their pension. Regarding the demographic change, this issue will be even more prevalent in the future. The current approaches, like the functional capacity evaluation, allow movement analysis of individuals, but are too time-consuming to be performed on all workers of a production site. This paper presents a method to assess the individual ability of a worker using a low-cost depth camera with full body tracking to determine the angles between body segments. A set of ergonomic exercises is used to demonstrate relevant abilities for assembly and commissioning tasks. By capturing the motion sequence of these exercises, a physical ability profile can be created with little effort.

Keywords

Ergonomics; Motion Analysis; Intel® RealSense™; 3D Depth Camera

1. Introduction

Demographic change has a major impact on the working population: the average age of working people in developed countries is increasing while the dependency ratio (the ratio of people of working age to those of non-working age) decreases. With an aging population, companies face a more and more challenging age structure which makes the efficient use of the workers' abilities more important than ever [1]. With repetitive motions and sometimes heavy work loads, assembly tasks promote musculoskeletal disorders, especially among older workers [2]. Thus, in order to prevent work-induced injuries, companies need to take into account the design of the work environment and assignment of employees to workstations.

Different approaches exist which aim to improve the ergonomic design of workplaces by analysing the physical stress on the worker's body, such as the Owako Working Posture Analysis System (OWAS) or the Rapid Upper Limb Assessment (RULA) [3,4]. All of these methods rely on motion analyses for the individual workplace without taking the worker's individual abilities into account. In contrast, a functional capacity evaluation (FCE) can measure the worker's physical capacity [5]. However, results from this evaluation show whether or not a worker can go back to work without taking the workplace into account.

Hence, workers with physical limitations or unusual body dimensions only benefit to a certain level from improvements derived with the OWAS, RULA or FCE.

This paper presents an approach to assess a worker's individual ability using a 3D-camera. With the Intel RealSense D415's full body tracking, the physical constraints of a worker can be determined by measuring the angles between body segments. The worker is recorded while performing a set of ergonomic exercises that demonstrate the range of motion (ROM) of joints typically strained in assembly. Based on an exemplary exercise, this paper shows how a physical ability profile can be created.

The development of an individual worker assessment is part of the research project ErgoTrack. The main research question is:

How can each worker's individual abilities be taken into account when designing workstations or allocating the workers among workstations?

In order to answer the main research question, the following questions need to be addressed:

- What is the individual physical capacity and flexibility of a worker?
- What are the workplace requirements for each worker?
- How can the physical ability profiles be matched with the workplace requirements?
- What is the individual musculoskeletal stress for each worker?

This paper only addresses the first research question partly.

2. Current state of research

2.1 Conventional ergonomics analysis

The conventional ergonomics analysis methods can be divided into methods that measure an individual's physical capacity and methods that analyse the workplace with its work sequence. The Functional Capacity Evaluation and the ERGOS® work simulator assess the physical capacity. During the FCE, a set of 29 standardised functional performance tests is performed. If required, additional work-specific tests can be added to the evaluation for certain work activities. The ERGOS® work simulator is a test station with 5 available units that each assess different capabilities, such as full-body movement. The FCE is performed in 5-6 hours over two days and the ERGOS® tests take 4-5 hours, excluding the time for evaluations and reports [5]. Both methods are therefore typically too expensive to be used on every worker of a production site.

For the workplace ergonomics analysis, among others, the OWAS and RULA can be considered state of the art. The OWAS consists of two parts. The first part is a method to evaluate working postures by observation in the form of work sampling. The second part defines a set of criteria for the redesign of working methods and places [3]. RULA is a method that assesses the postures of the neck, trunk and upper limbs which can lead to upper limb disorders. As a result, an action list is generated that specifies how much intervention is needed at each workstation in order to reduce stress on the body and thus the risk of injuries [4].

2.2 Ergonomics analysis using a 3D camera

A variety of approaches exist for ergonomic analysis using a 3D camera. Most research in this field was conducted with the no longer produced Microsoft Kinect and the corresponding Microsoft SDK. While some studies concluded that the Kinect is a reliable technology to measure the shoulder ROM [6–8], Huber et al.'s study [9] revealed concerns about using the Kinect's motion data if precise angles are required. Kitsunezaki et al. [10] and Fernández-Baena et al. [11] examined the Kinect's applicability for rehabilitation support and showed that it can be used for training monitoring and effectiveness. Furthermore, several systems have been developed that use the Kinect to perform a RULA in real time and give immediate feedback about the recorded person's posture in the form of a reliable RULA score [12–14]. The same has been done for the OWAS [15,16].

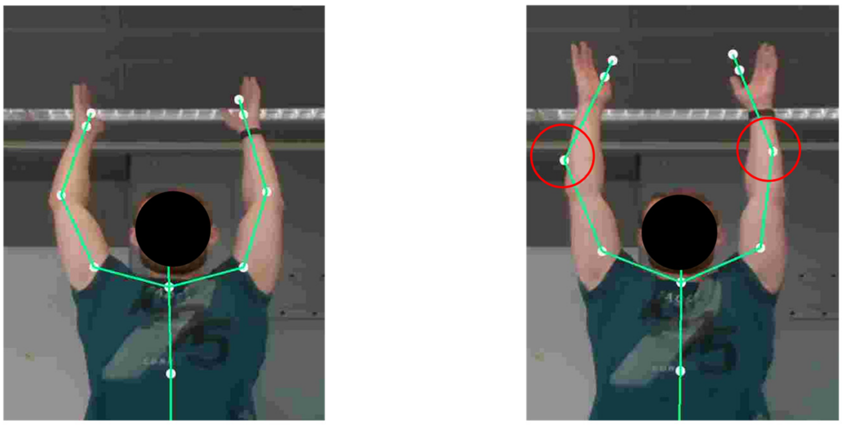
Instead of the Microsoft Kinect, we use an Intel RealSense camera, for which Siena et al. [17] reviewed the technology's technical capabilities and concluded that "the Intel RealSense system can be seen as a comparable if not superior alternative to the Microsoft Kinect".

3. Creating a worker-individual ability profile with a 3D camera

3.1 Experimental setup

In order to create a physical ability profile, the angles between body extremities are measured. For this purpose, a set of ergonomic exercises has been derived at the Institute for Biomechanics at the BG Unfallklinik Murnau, Germany. The exercises focus on the body parts that are subject to stress during assembly and commissioning tasks, such as the shoulders, elbows and spine. For this paper, one exemplary exercise was chosen that allows the measurement of the ROM for shoulder extension and flexion. The exercise and the corresponding angles are described in the next subsection. Each exercise is performed twice in succession to obtain reliable values for the ROM while keeping the expenditure of time low. The exercise was performed under the instruction that the subject should move their arms as far as they could. The exercise performance was only corrected if it differed significantly from the instructed movement. Minor rotations in the arm and/ or shoulder were tolerated.

19 subjects performed the exercise and analysis determined whether or not a reasonable angle can be deduced automatically. To determine if an angle is reasonable, a low-resolution screenshot of each recorded frame was captured. This allows the user to manually assess if the tracking of the required joints was performed correctly. Figure 1 shows an example of correctly tracked elbow joints (a) and falsely tracked elbow joints (b). The camera's technical accuracy is neglected in this test setup.



a) correctly tracked elbow joints b) falsely tracked elbow joints

Figure 1: Low-scale screenshots for data verification.

3.2 Ergonomics exercise

The ergonomics exercise for this paper aims to assess the ROM for shoulder extension and flexion in the sagittal plane. The sagittal plane divides the body into left and right parts and is represented by the y-z-plane, see Figure 2a). In the exercise, the subject completes a shoulder extension. This requires them to move their arms as far as possible behind the back and making sure the palms face each other. Afterwards, during shoulder flexion, the subject raises the extended arms forward and above the head, maintaining the palms facing each other. The ROM is the maximum angle between spine and upper arm in the sagittal plane of each movement, see Figure 2b).

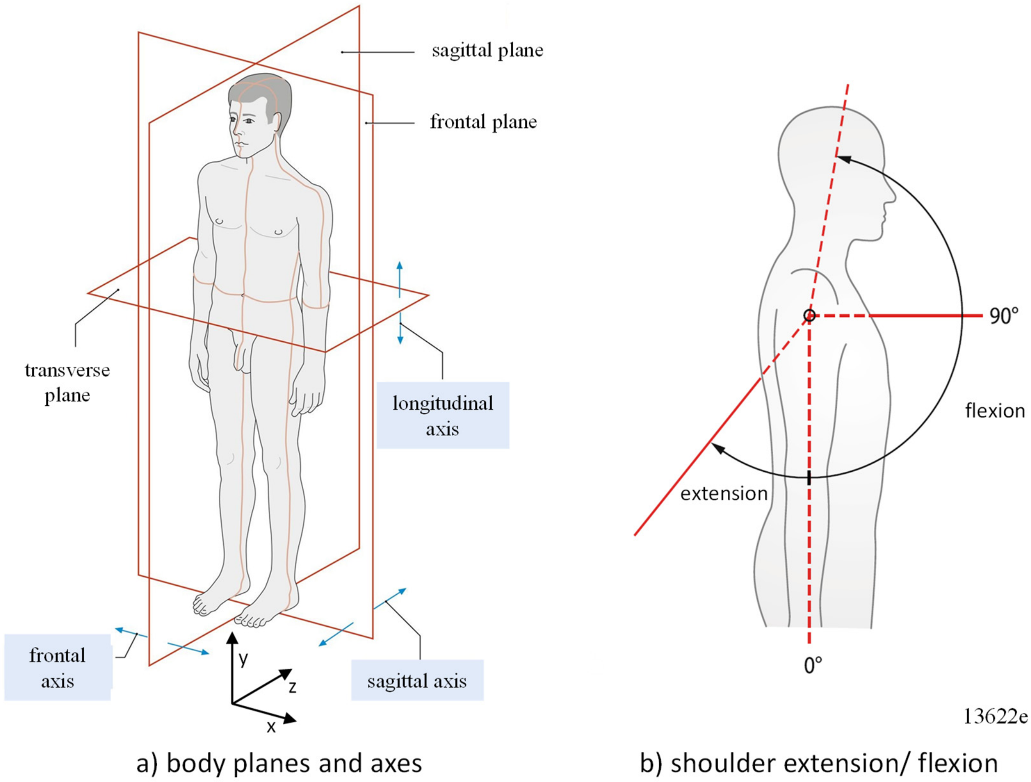


Figure 2: Body planes and axes [18] and shoulder extension/ flexion [19]

3.3 Data recording

3.3.1 Data Acquisition

For the data acquisition we use the Intel RealSense D415 and the 3D body skeletal tracking middleware Nuitrack SDK. Intel's 3D-camera uses infrared technology in order to create a depth map which is used by the Nuitrack SDK to approximate the position and orientation of 19 body joints. The orientation of each joint is described by a local coordinate system. For the data acquisition, the subject stands in front of the camera facing the lens. During the recording, the camera takes data at a rate of 15 frames per second to allow the processing of all relevant information. The Nuitrack SDK generates a value that describes the confidence in joint identification for each frame and each joint. The joint confidence is only given on a nominal scale, hence it only says whether the joint data can be trusted or not. This value is used for prefiltering the data, but preliminary tests showed that this filtering is not sufficient to exclude all false data from the analysis.

3.3.2 Angle Calculation

To create a physical ability profile we are interested in the extreme values of the angles taken during each ergonomics exercise. The exercise discussed in this paper requires the calculation of the shoulder extension and flexion angles shown in Figure 2b). Using the position and orientation data of the shoulder, elbow and torso joints, the angles can be determined for each frame recorded by the camera. Both angles are defined as the angle around the x-axis between the vector from the elbow to the shoulder joint, the upper arm vector, and the vector from the torso to the left collar joint, the upper spine vector (see Figure 3). In order to obtain only the angle around the body's transverse axis, all 3D coordinates are transformed onto the left collar joint's local y-z-plane, representing the sagittal plane, see Figure 2a).

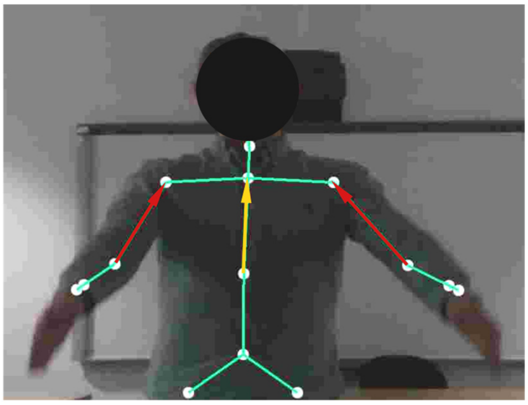


Figure 3: Vectors for angle calculation with the upper arm vector in red and the upper spine vector in yellow

4. Results and discussion

Overall, the results show that we can detect the shoulder ROM in the sagittal plane by recording only two repetitions of the exercise. 84.2% of the recordings' first maxima gave valid results, meaning the joints were tracked correctly when a maximum angle occurred (see Figure 1). The recording time ranged from 11 to 26 seconds (mean: 19.5 seconds). If the joint is not reasonably tracked on the first try, it can be assumed that either a joint was falsely tracked resulting in high angles at arbitrary frames or that the tracking was not working properly in the area where the angles' extreme values occur. The data showed that the latter was the case. Since the software displays the recorded frame when a maximum occurred, the observer can identify false recordings right after the exercise and let the examined worker repeat it. Given the fact that the success rate of a valid recording lies above 80% and the examinations only take about 20 seconds, the method is by far faster than conventional methods. Further, we believe that the tracking can be improved by optimizing the recording conditions, such as tight and white clothing and better lighting.

Figure 4 shows the cumulative distribution function of the measured angles for shoulder flexion and extension. The cumulative frequency that corresponds to an angle is the percentage of people whose ROM lies below that angle. The mean angles for shoulder flexion were higher than the expected values from literature, which are 180° for shoulder flexion and 45°-60° for shoulder extension [20]. One of the reasons for this is that the values from literature are determined in clinical ROM assessments, in which the examiner restricts the motion by controlling the subject's movement in a given plane. The captured screenshots show that the subjects did not only rotate their shoulders in the sagittal plane but also abducted them to allow a greater ROM. Since the derived angle is not intended to be used in a medical way, this circumstance is not disadvantageous. In fact, in order to assess the physical capacity for assembly and commissioning tasks, it is beneficial to assess the ROM from a rather natural movement, as these can be matched more easily with the workplace requirements. However, the additional shoulder abduction might not be the only reason for the high values. Future testing needs to show whether the measured values are correct or subject to systematic bias.

Even though the experiment was only conducted with a small sample, it shows the importance of an individual ability assessment. Both flexion and extension angles vary strongly among the participants. Assuming that the measured values are correct and that workers need a shoulder flexion of at least 180° during a certain overhead work task, 37.5% of the test persons would not be able to perform the overhead work due to their limited ROM in the right shoulder (see Figure 4b).

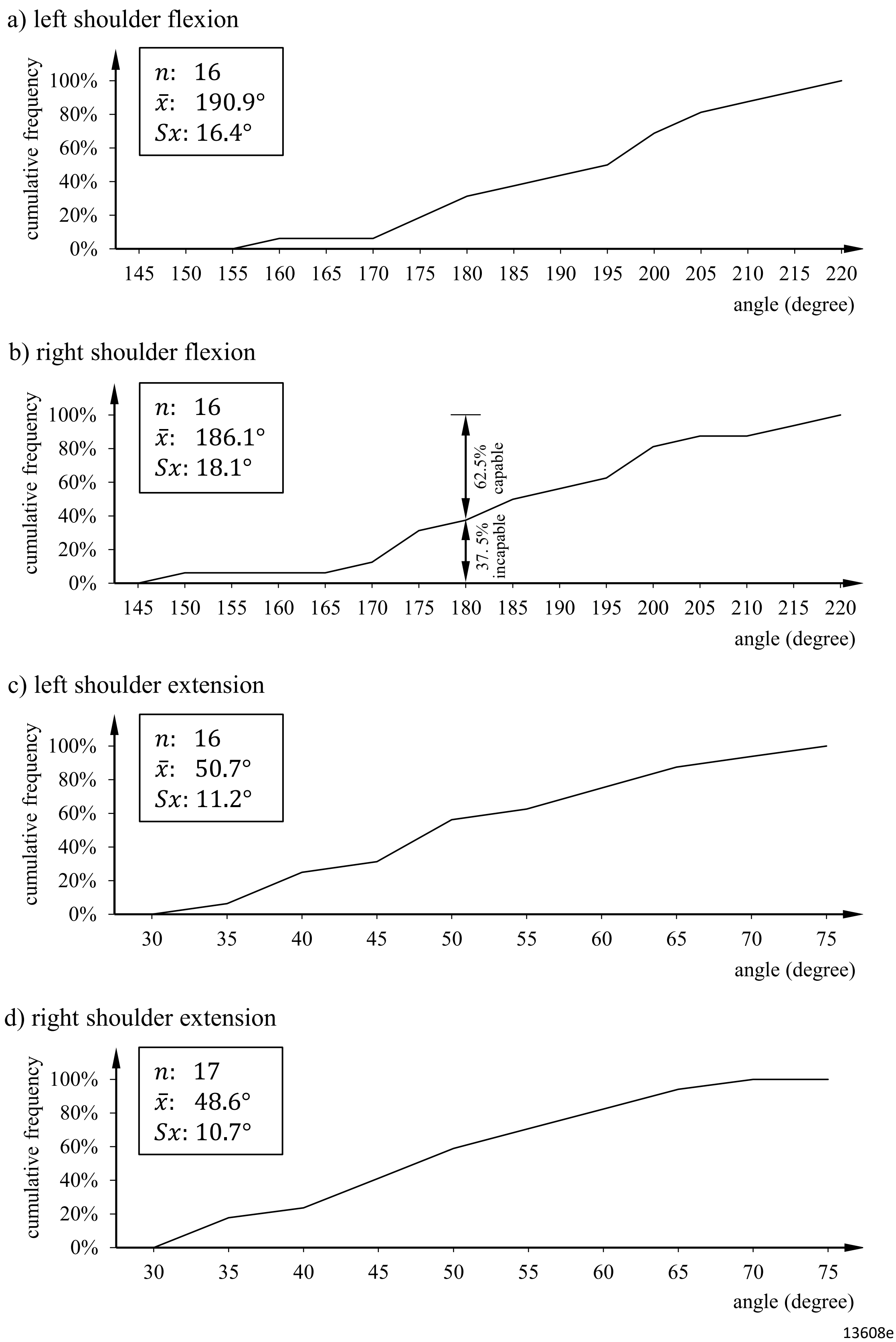


Figure 4: Cumulative frequencies of the measured angles with valid tracking. n is the number of measurements, $\bar{x}$ is the mean value, and Sx is the standard deviation.

5. Summary and Outlook

This article presents an ergonomic analysis method in which a depth camera is used to assess the individual abilities of a worker within a short time. Based on the example of a shoulder ROM measurement, we were able to demonstrate that it is possible to assess a worker's movement ability by letting him perform two repetitions of an ergonomics exercise with an average recording time of 19.5 seconds. The experiments showed that the shoulder ROM varies strongly among the participants. That underlines the need of an individual ability assessment in assembly and commissioning. Looking at the cumulative frequencies of the measured angles, the assessor can easily see how many people can perform certain movements. For example, 37.5% of the participants are not able to perform overhead work tasks that require a shoulder flexion of 180° or above. Further testing is required to expand the method onto other ergonomic exercises to create a complete physical ability profile that can be matched with workplace requirements. The workplace requirements are planned to be assessed with an Xsens motion capture suit since current 3D cameras show weaknesses with the assessment of workstations due to bad lighting conditions and occlusion of relevant joints.

The absolute angles that we measured were higher than the values we would have expected from literature. Even though these values can be at least partly explained by the different forms of measurement, the system's accuracy needs to be investigated. While several studies examined the accuracy for angle measurements with the Microsoft Kinect camera, there have been no studies on the accuracy of the Intel RealSense D415 with the Nuitrack SDK.

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Biography

Justus Brosche (*1993) studied Mechanical and Process Engineering with a focus on production management at the TU Darmstadt. He started working as a research associate at the Institute of Production Management and Technology at the Hamburg University of Technology in 2018.

Hannes Wackerle (*1993) has been research associate at the Institute for Biomechanics at the BG Unfallklinik Murnau, Germany, and Paracelsus Medical Private University Salzburg, Austria, since 2017. He has studied Sports Science and Ergonomics – Human Factors Engineering and is a member of scientific societies of sports science and human movement analysis.

Hermann Lödding (*1971) studied Industrial Engineering and Management at the University of Kaiserslautern and completed a PhD in Engineering at the University of Hannover. From 2004 to 2009, he was working for Robert Bosch GmbH. Since 2009, he has been working as a professor for production management at the Hamburg University of Technology.