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Integrating Motion Capture Technology into Ergonomics Design: Managerial Implications for Systemic Safety Management

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Abstract: In the era of increasing attention to ergonomic work organization (which also affects employee safety), ways are being sought to improve and detail ergonomic analyses aimed at proposing ways to improve working conditions. One such method may be the use of Mo-Cap technology, which allows for examining the position of employee body segments while performing key activities at work. The findings are at least partially compatible with ergonomic assessment techniques, e.g. REBA, in order to obtain a more accurate analysis resulting from better recognition of work planes. The presented article focuses on recognizing the possibilities of using Mo-Cap in ergonomic analyses on selected examples. The positive aspects of the application were identified (e.g. better recognition of the employee's body position during work) as well as limitations (e.g. lack of possibility to translate the ad-reading into determining the angles of the body segments' position). The results support the use of ergonomic assessment methods. They are also analyzed in relation to the benefits and barriers of using Mo-Cap technology in ergonomic analyses.

Keywords: ergonomics; motion capture; system work safety

1 INTRODUCTION

In companies (especially manufacturing ones), there is an increase in awareness of the appropriate design of workstations and the need to improve the quality of ergonomics of existing ones. With increasing awareness, employers attach increasing importance to the work environment in which their employees spend time and work every day. With the well-being of employees in mind, workstations are increasingly assessed in terms of their functionality and ergonomics. It happens that existing workstations, despite fulfilling their function in relation to the process, do not provide ergonomics, and therefore may cause ailments in employees. In a situation where employers decide to introduce changes to existing workstations in order to improve the comfort of employees' work, we are dealing with so-called corrective ergonomics, which deals with the analysis of existing workstations in terms of their adaptation to the psychophysical capabilities of employees [1, 2]. In order to analyze workstations, ergonomic assessment of workstations is performed. This assessment can be carried out using well-known methods and tools such as REBA, RULA, OWAS, 3DSSP [3] or applications measuring angles, e.g. Navo Smart. Each method has a specific purpose and evaluation principles, and each method has its limitations. These limitations are particularly important in standard assessments - they usually result from a subjective approach to the appropriate determination of risk, e.g. the position of a given body segment or the determination of the frequency of performing a given activity [4]. For this reason, ways are sought to objectify the assessments and provide a more accurate description of the work before starting the ergonomic assessment using the selected method [5].

This article examines the possibilities of using Motion Capture technology (Neuron Perception system with Axis Studio Quick Start Guide software) for ergonomic evaluation of selected production workstations and determines the justification, benefits, and limitations of using this technology in this case. The aim of this work is to assess the potential of Mo-Cap in precise monitoring and analysis of employee movements, which can contribute to improving ergonomic assessment processes and support traditional methods, becoming an integral part of Systemic Safety Management.

2 APPROACHES USED FOR ERGONOMIC ASSESSMENTS IN PRODUCTION WORKSTATIONS

2.1 Selected Methods of Ergonomic Assessment

In ergonomic assessment, various methods are used, usually adapted to the assessed workstation in terms of the employee's position at work or the occurrence of a specific type of load that should be examined. Among them, we can distinguish methods in which data related to the employee's effort is processed, e.g. heart rate monitoring or electromyography [6], but their use is limited due to the need to have appropriate equipment and to perform measurements over a long period. For this reason, methods based on observation are more popular, based on which an assessment is made according to the instructions and the scoring provided in the method. Among the known and frequently used methods, it is possible to distinguish [7-9]:

- methods based on the assessment of the position of body segments while performing specific key activities at workstations, e.g. RULA, REBA, OWAS,
- methods for assessing a given employee's workload, e.g. carrying or lifting; these include: NIOSH Lifting Equation or MAC,
- methods focusing solely on a given body segment, e.g. the work of the wrists and hands (e.g. Strain Index or OCRA),
- questionnaire methods and methods based on the employee's assessment of their ailments on an adopted assessment scale.

In the case of each method, limitations in their use are noted, especially in the area of correct reading of the position of the body segment or determining angles, e.g. rotation or collection of work materials. For this reason, the use of these methods should be performed by an experienced observer and supplemented with additional measurements in order to assess as accurately as possible [10].

2.2 Advanced Technologies in Ergonomic Assessment

In ergonomic assessment, methods that go beyond the standard are increasingly used, in which it is possible to model the workstation by supplementing appropriate parameters. This allows for a more accurate assessment and obtaining a report on the most hazardous activities for the employee during work. An example of such a method is 3DSSPP, where it is possible to model the workstation and precisely determine the parameters necessary for evaluation, e.g. angles [11]. Another example is the modelling of the workstation and ergonomic assessment using the JACK system, in which it is possible to obtain a report on the employee's workload based on the introduction of appropriate parameters related to the employee and the work environment [12]. Elements of machine learning are also increasingly used for ergonomic analysis. This allows for automatic calculation of results based on snapshots or digital video using computer vision and machine learning techniques. The use of such a solution helps to reduce the subjectivity of ergonomic assessments and also allows for the assessment of several workstations at once using an appropriate number of recording devices [13]. An interesting, new direction of development of ergonomic assessments is the use of artificial intelligence elements in this process. Thanks to the automation of assessments, it is possible to quickly diagnose the position of employee body segments and quickly analyze the obtained data, often together with proposals for introducing corrective changes at the workstations. AI also supports the establishment of an employee training strategy in terms of ergonomics and supports the creation of short- and long-term plans in the context of increasing the ergonomic quality of workstations [14,15].

2.3 The Use of Mo-Cap in Ergonomic Assessment

There is a growing interest in the use of Motion Capture in ergonomics. This technology allows for precise recording and then analysis of the position of objects or characters in the real world. This data is then processed into a digital format [16]. There are two models of Mo-Cap technology:

- optical systems operating on the principle of infrared light sent from cameras to markers,
- inertial systems - based on sensors placed on costumes or on the human body.

The sensors are equipped with an accelerometer, magnetometer and gyroscopes, which create an autonomous system without reference points (as in the case of the optical system) [17]. The following benefits of using mo-Cap in ergonomics are noted:

- improving the speed and accuracy of collecting movement data,
- creating conditions very close to real life,
- processing many data simultaneously,
- the possibility of partially translating, the obtained results into standard ergonomic assessment methods [18].

Certainly, the limitation of using Mo-Cap for ergonomic assessments is the availability of hardware and software as well as the lack of appropriate knowledge on how to use them. Another problem may be the lack of possibility to fully transfer the results to the selected ergonomic assessment method.

3 METHOD OF RESEARCH

In the undertaken research, an ergonomic analysis of the selected workstation was conducted. Standard ergonomic methods were used, such as the 3DSSPP method, REBA and RULA based on data obtained from the use of Mo-Cap technology. The Neuron Perception Studio was used. It is a system and software based on Inertial Measurement Units (IMUs) integrating accelerometers, gyroscopes, and magnetometers to track movement in three-dimensional space. In Neuron Perception system are used 17 wireless sensors placed on key body joints to provide real-time motion data transmission via Bluetooth protocol. The Perception Neuron Studio (PNS) was used due to its high flexibility, portability, and resistance to magnetic interference, this system has been widely used in animation, virtual reality, biomechanics, and sports science, proving to be an efficient alternative to optical-based Mo-CAP solutions. PNS offers several advantages for ergonomics, including its cost-effectiveness and user-friendly setup compared to traditional optical systems like OptiTrack. Its high consistency in measuring upper-body kinematics, with CMC values ranging from 0.73 to 0.99, allows for accurate assessments of movement patterns. Additionally, the PNS can capture data across various task complexities and movement speeds, making it suitable for comprehensive ergonomic evaluations in biomechanical research [19].

The first stage of the research was preparing the equipment and reading the instructions for its use. The following research techniques and methods were then used:

1) Direct observation.
2) The use of Motion Capture technology using the Perception Neuron set.
3) Recording of selected activities using cameras.
4) Measurement of forces using a dynamometer (context data for assessment) - FB2K AXIS dynamometer ensuring measurement accuracy of ±0.1% of the range.
5) Analysis of results and comparison with applicable standards and regulations.
6) Biomechanical analyses using the 3DSSPP program and the REBA or RULA methods.

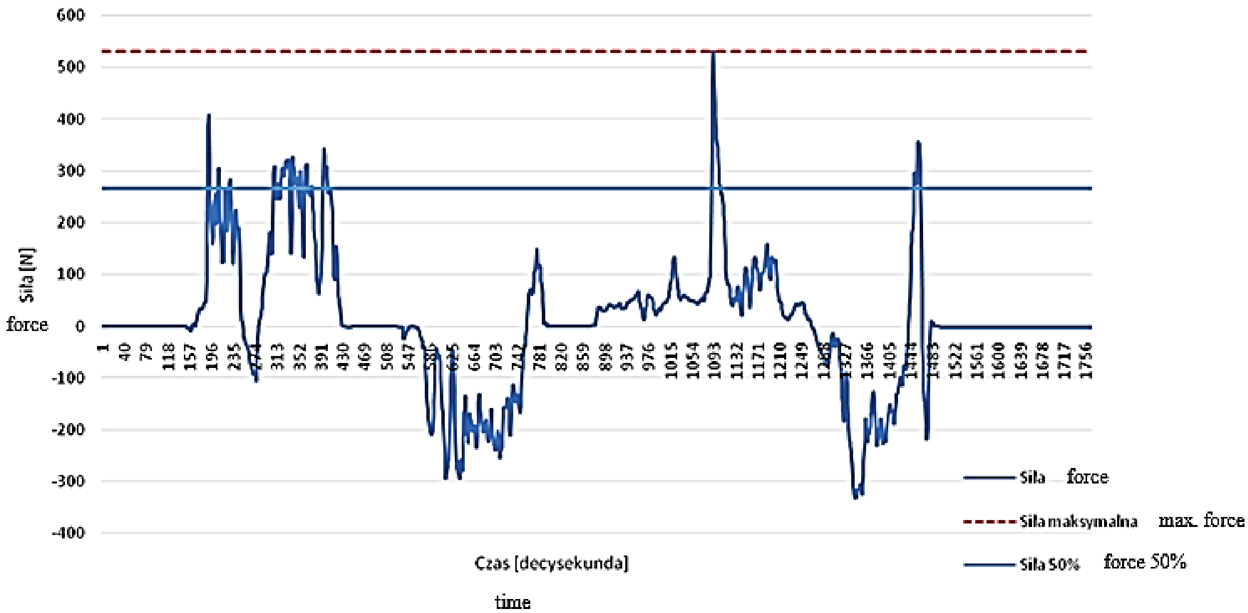
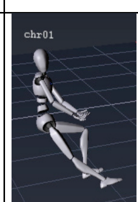
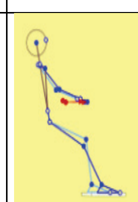
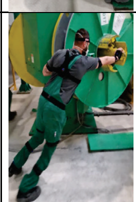
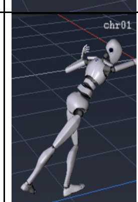
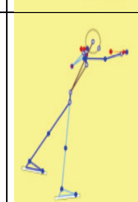
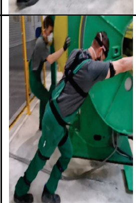
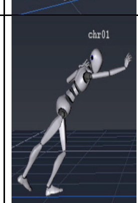
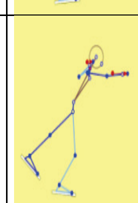


Figure 1 Forces measured at the selected workstation using a dynamometer

The results obtained in the studies were analyzed in terms of the consistency of the data obtained through the Mo-Cap assessment with the standard assessment and the potential of using this technology in ergonomic assessments was determined.

Table 1 Results of selected workstation assessments

Activity	Picture	Mo-Cap	3DSSPP	REBA Score
Pulling reel 1				12 - very high risk
Pushing reel 1				11 - very high risk
Pushing reel 2				12 - very high risk
Pulling reel 2				12- very high risk

Source: own elaboration

4 RESULTS

In order to achieve the aim of this research, i.e. to indicate the potential of using Mo-Cap technology in ergonomic assessments and in systemic management of employee safety, a production workstation with pushing and pulling activities was selected for assessment. Fig. 1 presents the values of forces measured using a dynamometer for contextual indication of the employee's load. Then, four key activities performed by the worker were shown, taking into account the motion capture reading and 3DSSPP and REBA assessment.

Tab. 1 indicates the key activities performed by the employee along with selected assessments.

To show an example of the evaluation result for activity 1 "Pulling reel 1", Fig. 2 presents the full report of the 3DSSPP evaluation.

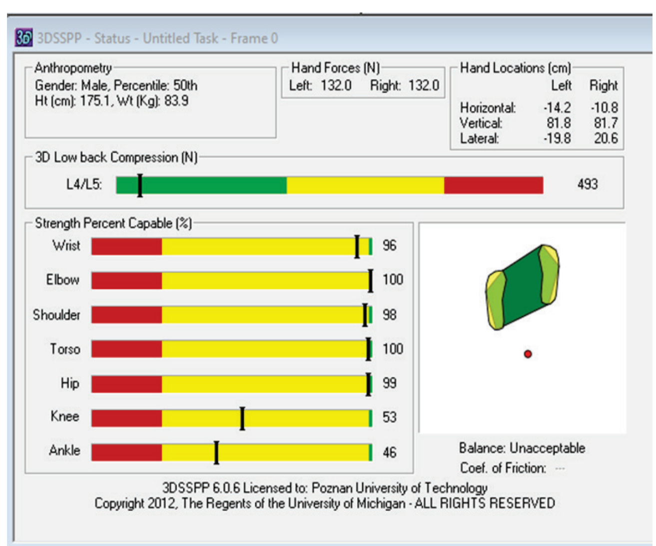


Figure 2 3DSSPP assessment result for the activity "Pulling the reel 1"

It can be stated that the Mo-Cap reading results are similar to the camera-recorded performance of the activity. Similarly, the model presented using 3DSSPP reflects the actual activities performed by the employee. It is also worth noting that Mo-Cap can be used to read the body position when performing activities at high speed and requiring the employee to apply a lot of force.

5 DISCUSSION

In determining the possibility of using Mo-Cap for ergonomic analyses, attention should be paid to errors and irregularities that may occur during the testing (and also occurred in the analyzed example).

1) While reading the data and tracking the 3D model generated in the program, an irregularity was noticed - one of the sensors lost connection with the transmitter, which resulted in an incorrect starting position of one of the joints (Fig. 3).

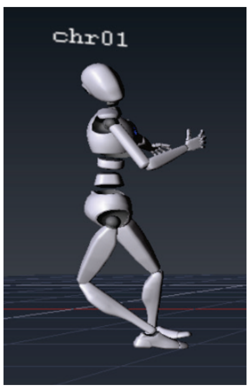


Figure 3 Uncalibrated sensor view shots [source: Axis Studio Program]

2) Another limitation was the lack of the ability to read the angles between the joints. This function was necessary for precise ergonomic assessment using Motion Capture technology. The Axis-studio software, which is the target software for the Neuron Perception mapping set, does not assume such a function. After multiple attempts, it was decided to use other programs for reading the mapped data.
3) Technical problems were encountered during the measurements. The equipment required frequent calibration, which was not always successful. Because of incorrect connection of the sensors with the transfer, it was necessary to repeat calibration attempts, which required additional time (Fig. 4).
4) In the analyzed case, bands requiring additional attachments were used, with the help of which the sensors could be attached in appropriate places. The process of dressing the employee in bands and installing the sensors turned out to be a time-consuming task, and it required the input of the employee and a third party who had to attach the sensors to the employee's body and activate them.
5) The unreliability of the sensors and their disconnection during the test turned out to be one of the greatest limitations. In the event that the test was not repeated and recorded with a camera, it could have been impossible to obtain data for processing.

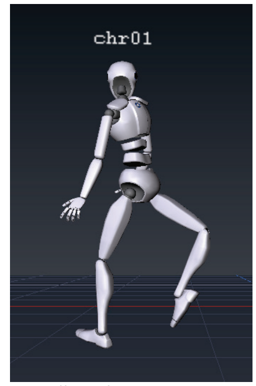


Figure 4 A shot showing the effect of losing connection between the sensor and the transmitter [source: Axis Studio Program]

Based on the analyzed example, it is also possible to indicate the positive aspects of using Mo-Cap in ergonomic assessment:

1) The employees were interested in the course of the research using Mo-Cap. The generated 3D model aroused the interest of the company, and the presentation of the results gained additional attention and curiosity. The 3D model was used to present the entire process, based on which it was possible to explain the source of the reported ergonomic problems.
2) Direct contact with employees, which was necessary due to the specific nature of the research, conducted using Motion Capture technology, turned out to be extremely valuable. Thanks to this, it was possible to overcome communication barriers and obtain additional, often very useful information about the course of the work process. Employees were more willing to share their observations, which allowed for a deeper analysis of the ergonomics of their workstation.
3) Employers, observing the presented silhouette model generated by Neuron Perception software, could see that employees' comments regarding their workstations were justified. Thanks to precise visualization, it was possible to notice ergonomic irregularities that could have been previously underestimated.
4) Another benefit of being able to show a 3D model of work is the possibility of educating employees. The 3D model provided a clearer visual aid for employees to identify ergonomic improvements in their workspace. This type of tool allows to indicate places where work is not performed in accordance with ergonomic principles, which is often omitted in traditional analyses.

A further direction of work on the undertaken research could be to identify the possibilities of using artificial intelligence to overcome the problem of measuring angles in the application of motion capture in ergonomics.

6 CONCLUSIONS

The analysis of the study results showed both the potential and limitations of using Motion Capture technology in ergonomics, which allows for a better understanding of its applications in practice and in systemic safety management in an organization. It can be undoubtedly stated that it brings great benefits, especially in modeling the work of an employee, which can then be translated into standard methods of ergonomic assessment. Unfortunately, such translation must be done independently, which may require additional time in the analyses. A major barrier to overcome is certainly the lack of precise reading of the angles of employee body segments, which is what most ergonomic assessments are based on. This creates a requirement for additional software. It can be noted that the recognition of the possibilities of using Mo-Cap in ergonomics is the subject of scientific research. Researchers note similar difficulties in implementing this technology, at the same time they note its importance in an individual approach to the assessment of each employee (which, for example, estimation methods do not provide). The potential solution to the limitations is the use of additional supporting software or a detailed definition of the purpose of the Mo-Cap assessment and the scope of applicability [20, 21].

To sum up, it can be stated that the use of Motion Capture in ergonomics is possible and beneficial from a practical point of view, if appropriate resources are established and additional elements are provided to enable reliable assessments. This may require the assessor to perform a time-cost calculation and decide whether the benefits outweigh the resources needed to eliminate the barriers. Certainly, in some cases (e.g., a systemic assessment of all workstations in an organization), it may turn out that the use of Mo-Cap will be problematic due to the long time required to set up and connect the equipment. In other cases, it may be an advantage (e.g., getting employees interested in the assessment process or convincing the company's management to change by visually presenting problems). These benefits are of particular importance in systemic safety management, which includes ergonomics. It requires the involvement of all participants in the organization to be carried out successfully and improved constantly.

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