CHEMICAL ENGINEERING TRANSACTIONS

VOL. 58, 2017

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Remigio Berruto, Pietro Catania, Mariangela Vallone

ISBN 978-88-95608-52-5; **ISSN** 2283-9216

DOI: 10.3303/CET1758006

Ergonomic Checks in Tractors through Motion Capturing

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The evaluation of the ergonomic design of driver cabins is often done by asking subjects. This paper describes a proposal for a motion capturing method that allows an objective analysis and evaluation of gripping areas and of the accessibility of control elements. A camera films subjects while they are executing use cases. Simultaneously, the positions of their joints in space are measured. These positions allow the calculation of the joint angles based on the frames of the camera. Finally, comparing them with comfort angles from the literature allows the ergonomic evaluation of gripping areas. In particular, this paper explains the motion capturing process itself, the concept for an evaluation procedure of the captured motions, and a statistical model to validate the whole method with subjects.

1. Introduction

The ergonomic design of the driver cabin is decisive for more than every second customer when purchasing an agricultural tractor. This finding is from a survey conducted by the Institute of Agricultural Engineering in 2016 (n = 853). The high significance of the cabin design is not surprising because it provides the human machine interface and the driver spends most of the time in the cabin while using the machine.

With the design of the cabin, manufactures not only try to meet ergonomic requirements but also try to use the design as a brand specific element in order to differentiate themselves from competitors. For this reason, there are many design variants based on the manufacturers' philosophies, although the functional characteristics of tractors are almost similar. In a given use case, the motion sequence of the driver in a cabin of manufacturer A differs from that in a cabin of manufacturer B. The challenge is to evaluate the different cabin designs regarding their ergonomic quality.

One can numerically and thus objectively measure and evaluate many features of agricultural tractors. However, the ergonomic assessment of a driver cabin by means of subjects and questionnaires is strongly influenced by the impression of a subject and is therefore not objective. The experiences of a subject already made with a manufacturer can influence the result. The same applies to personal aesthetic preferences or beliefs how certain features have to be designed in a cabin.

Based on the explanations above, an objective ergonomic test and evaluation of a cabin design can lead to better and more reliable results both in the development process and when evaluating cabins that are already on the market. By basing the evaluation of body postures and motions on comfort angles from literature, objective testing and evaluation of cabin designs can be achieved.

Marinello (2014) also proposed an approach for ergonomic analyses in tractors with a motion capture camera. His paper focuses on the velocity of the moving joints. In this paper however, the joint angles are used for an ergonomic analysis and evaluation. Furthermore, a concept for a classification system to evaluate the measured motion is given in this paper.

2. Classification of the method into the overall context of the cabin

Looking at the cabin as a whole, it has four main functions as shown in Figure 1.

- Safety in the event of accidents:
  The cabin must protect the driver sufficiently against mechanical impact in the case of accidents. At this point, the safety standards rollover protective structure (ROPS), falling object protective structure

Please cite this article as: Schempp T., Bottinger S., 2017, Ergonomic checks in tractors through motion capturing, Chemical Engineering Transactions, 58, 31-36 DOI: 10.3303/CET1758006

(FOPS), and operator protective structure (OPS) can be listed as well as restraining systems on seats.

- Protection against influences from the work environment:
  The driver has to be protected against all influences from the work environment that are harmful to health or performance. These are in particular the climate, toxic substances, noise and vibrations.
- Comfort:
  The comfort includes facilities such as radio, cup holder, storage et cetera.
- Workplace for the fulfillment of the work task:
  The ergonomic design of a workplace comprises cognitive and physical ergonomics. The aim is that the driver can carry out all work tasks at his workplace under appropriate cognitive and physical stress.

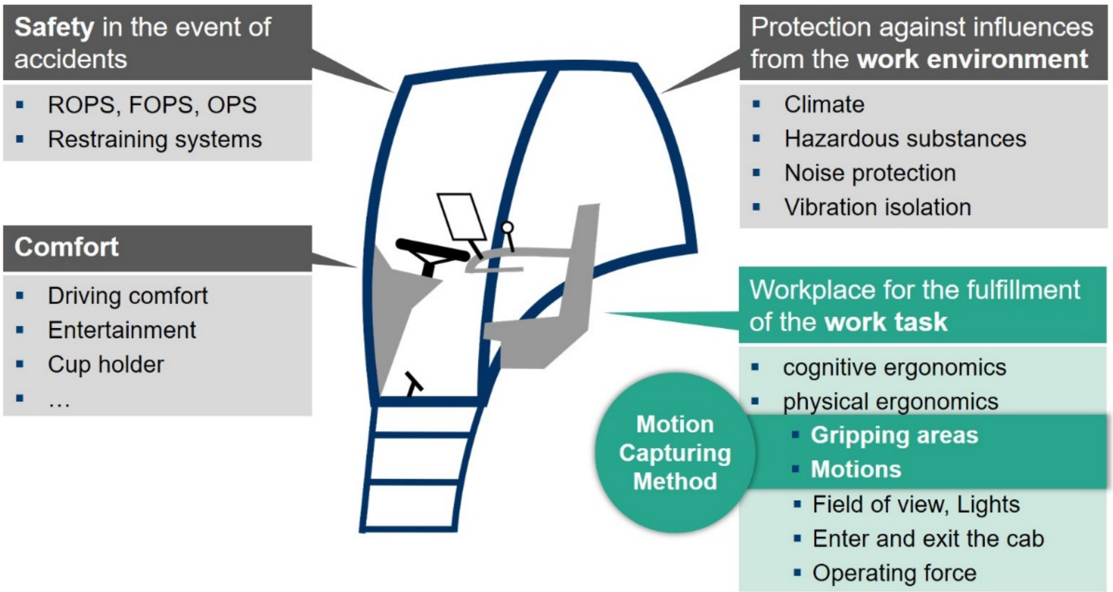

Figure 1: The main functions of a driver cabin. The motion capturing method covers the marked parts.

The motion capturing method in this paper belongs to the physical ergonomics of the main function "workplace for the fulfillment of the work task". In this case, the reduction of the physical load defines the quality of the workplace for the fulfillment of the work task. The load is positively correlated to the stress of a driver. Although the absolute level of stress is individually based, the reduction of physical load at the same time lowers the individual stress to maintain the driver's performance for a longer period of time. A human-oriented workplace design regarding gripping areas and the accessibility of control elements ensures natural body postures during work and an appropriate physical load for the driver.

3. The motion capturing process

For the digital and objective detection of body postures and motions, various methods are listed and described in Bubb (2015). Here, an optical motion capturing method without markers is used. Optical and marker-less methods have the advantage that no angle sensors or markers need to be placed on the subject. However, the necessary optical accessibility to all joints is a disadvantage.
A further disadvantage is the small variability of the distance between the measured joint points or rather the length of the body elements. To capture the motions a Microsoft Kinect v2 camera is used.
Figure 2 shows the integration of the camera and the whole motion capturing method.

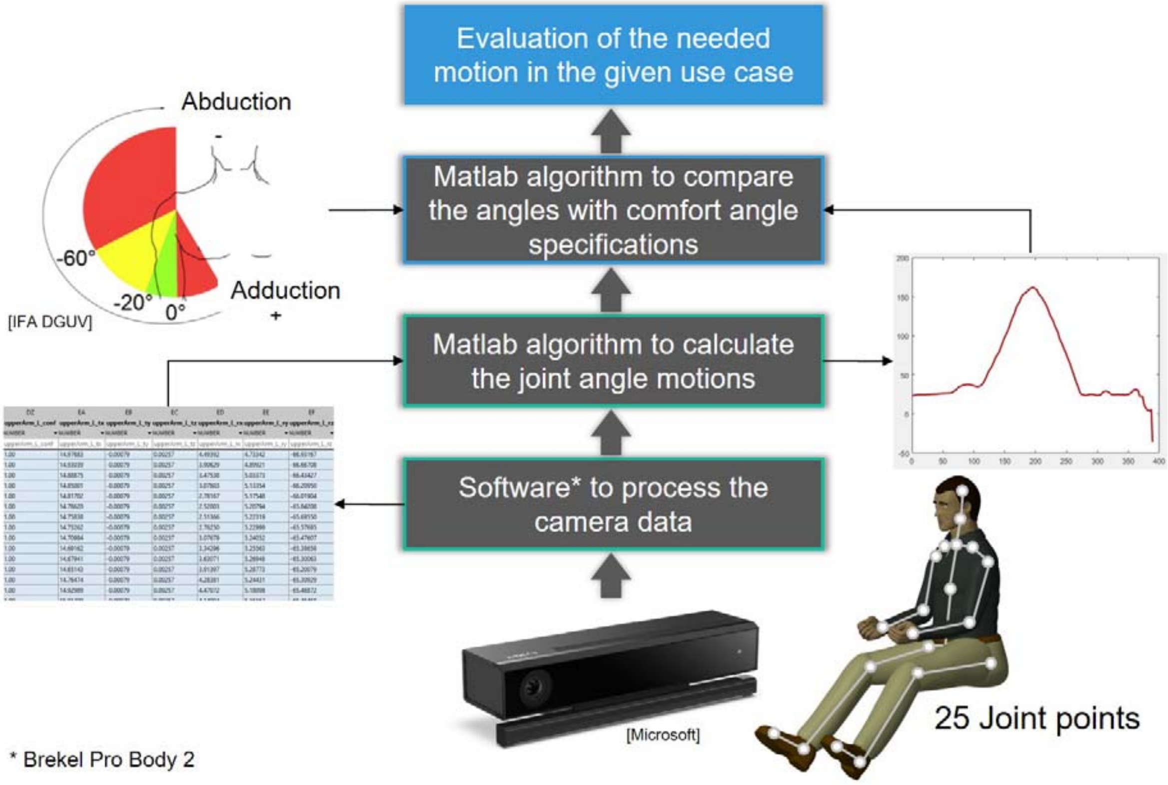

Figure 2: The motion capturing method based on a Kinect v2.

The camera can place up to 25 joint points on the filmed subject and determines their positions in space with 30 frames per second. For each body element, a local Cartesian coordinate system (COSxyz) is calculated of which one coordinate axis lies in the longitudinal axis of the belonging body element. The orientation of a local COSxyz of a body element always refers to the local COSuvw of the more proximal body element. The hip point is the top-most parent of the body element hierarchy of the whole body. The orientation of a COS is described by means of Eulerian angles of rotation, which result from rotating a local COSxyz about the axes of its parent COSuvw in the order u-axis, v-axis and w-axis. The origin of a local COSxyz of a body element lies on the longitudinal axis of the more proximal body element. Hence, the length of a body element is the magnitude of the vector from the origin of his local COS to the origin of the local COS of the more distal body element.

Figure 3 exemplarily depicts the arrangement of coordinate systems for the shoulder and elbow joint.

With the example of the abduction and adduction of the shoulder joint in the frontal plane of the body, the calculation of the joint angles is explained. The vector a_{xyz} describes the length and position of the upper arm and is defined as follows:

$$\boldsymbol{a_{xyz}} = \begin{pmatrix} x_s \\ y_s \\ z_s \end{pmatrix} \quad (1)$$

The rotation matrices R_u, R_v, and R_w describe the rotation of the local COS_{xyz} of the upper arm with the axes x_s, y_s, and z_s around its parent COS_{uvw} of the shoulder with the axes u_s, v_s and w_s. The coordinate transformation

$$\boldsymbol{a_{uvw} = R_w R_v R_u a_{xyz}} \quad (2)$$

converts the vector a_{xyz} into the parent COS_{uvw} of the shoulder with the axes u_s, v_s, and w_s. By means of a projection of the vector a_{uvw} into the u_s-v_s plane of the shoulder, the angle to the coordinate axis v_s can be calculated, which is the joint angle for abduction and adduction. The magnitude of the vector a_{xyz} is the length of the upper arm.

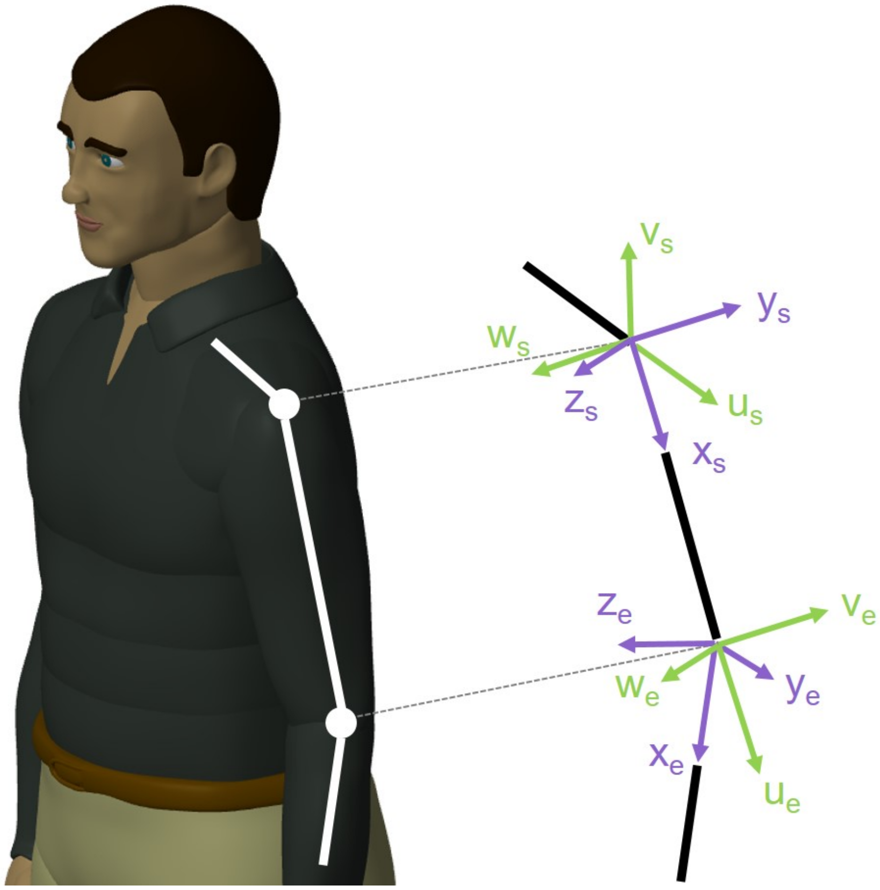

Figure 3: Arrangement of coordinate systems of body elements such as for the shoulder (index s) and elbow (index e) joint.

4. The motion analysis and evaluation

With the captured motion of a subject, it is possible to analyze the joint angles in a way that Figure 4 depicts: The graph illustrates all joint angle motions for the right shoulder and elbow based on time for two repetitions of the use case "steering wheel to joystick to side panel and backwards". By having two times the same use case in this graph, one can see the repeating accuracy of the camera is very good.

A Matlab algorithm then conducts the ergonomic evaluation of the captured motion. As stated in Figure 2, the algorithm compares comfort angle specifications from literature to the calculated joint angles. For this, the traffic light evaluation system from the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA, 2013) is used in the algorithm. The evaluation with the traffic light system is based on three criteria namely green, yellow, and red.

The concept for an adaption of the traffic light evaluation system to the method and the processing of the joint angle data is depicted in Figure 5. First, all joint angle values are evaluated with a color in every frame. By averaging frames of the same color over all frames, the percentage distribution of the colors is determined for each joint angle motion. Second, the percentage distribution of the colors for the whole body motion results from the sum of the percentage values of the same color divided by the number of joint angles taken into account. To classify the result the classification system from VDI 2225 is applied. For the classification, only the percent value of the green color is taken into account: If the value for the green color is above 80%, the design of the gripping area for the given use case is good. If the value for the green color is above 60%, the design of the gripping area for the given use case is acceptable. For a value below 60%, the design of the gripping area for the given use case is not acceptable.

Besides the traffic light evaluation system, there are other evaluation systems for body postures like the "Rapid upper limb assessment - RULA" (IFA, 2009) et cetera. In the long term, other evaluation systems shall be adapted to the algorithm. First, however, a validation of the evaluation concept in Figure 5 is necessary. For this purpose, a statistical model was developed based on tests with subjects. This model can be used to validate different evaluation systems or the way in which they are adapted to the algorithm.

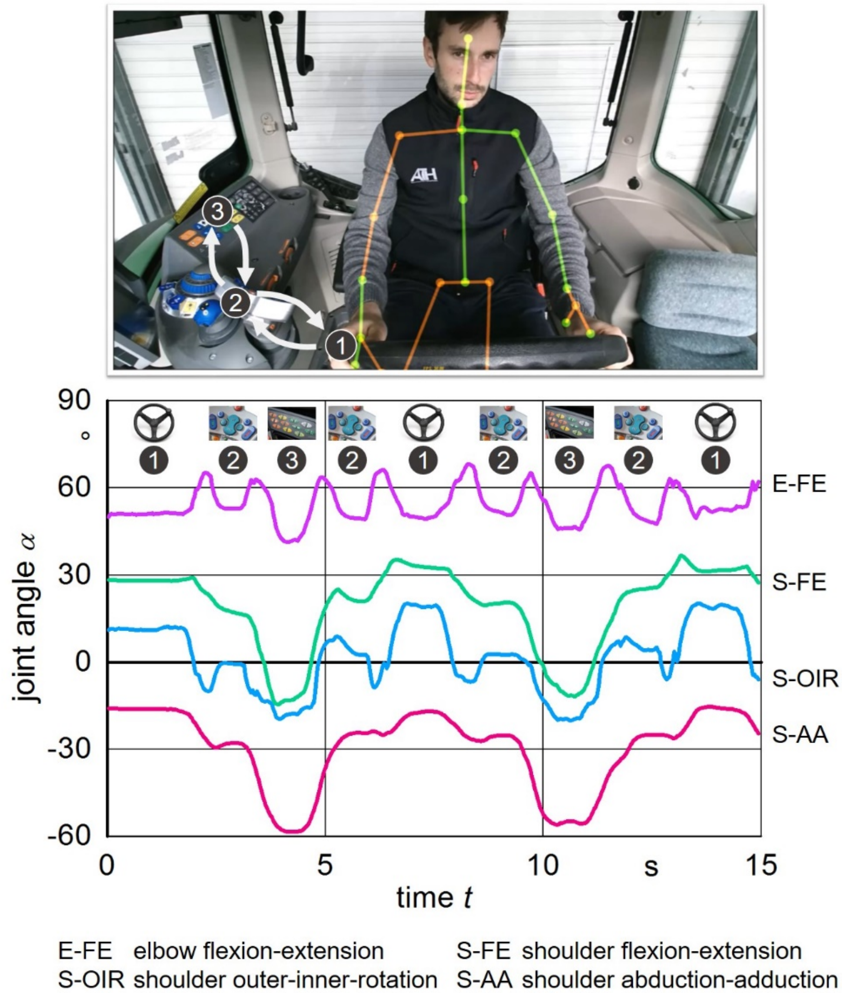

Figure 4: Joint angle motions for right shoulder and elbow based on time for two repetitions of the use case “steering wheel to joystick to side panel and backwards”.

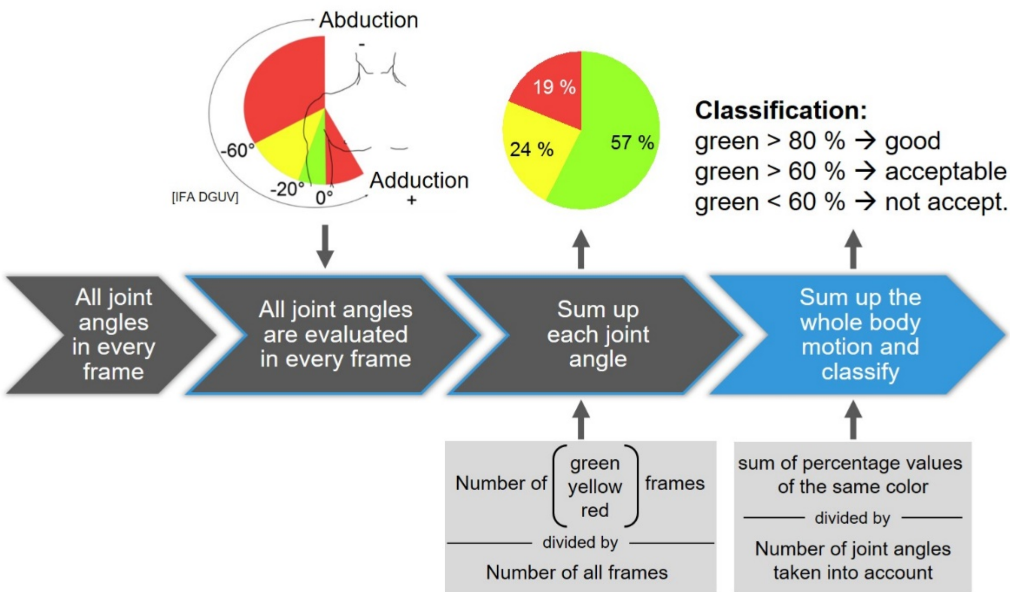

Figure 5: The concept for processing the joint angle data using the traffic light evaluation system as the base.

5. Statistical validation of the evaluation system of the method

A statistical validation model based on subjects was developed to check, a) if the actual feelings of the subjects comply with the results of the proposed evaluation algorithm, b) if there is a better way to adapt the evaluation system to the algorithm, and c) to have a statistical model to validate other evaluation systems for the method. For this sake, 17 use cases (body postures and motions) in a Fendt Vario 313 Panorama Cabin were defined which 28 subjects (22 male, 6 female) had to evaluate on a percentage scale (n = 476 observations).

The null hypotheses for the validation model was:

- The results of the traffic light evaluation system or of another evaluation system in the algorithm do not comply with the feelings of the subjects.

The variables for the statistical model are:

- The feeling of a subject recorded on a scale as the response variable
- ID of a subject as a categorical predictor variable
- Gender of a subject as a categorical predictor variable
- Age of a subject as a continuous predictor variable
- Body height of a subject as a continuous predictor variable
- Use case number as a categorical predictor variable
- Result from the evaluation algorithm as a continuous predictor variable

To avoid controlling for the experience and knowledge that a subject has about a tractor with another variable, the use cases were explained to the subjects before the study in a way that they knew where to go with their hands. Because of controlling for by-subject variability and by-use-case variability, the variables for subject ID and use case are defined as random effect factors. The gender is treated as a fixed effect factor. Age, body height, and the result from the evaluation algorithm are covariates. To account for random and fixed effects a linear mixed effect model with the following equation was applied:

$$\boldsymbol{y} = \boldsymbol{X\beta} + \boldsymbol{Zb} + \boldsymbol{\epsilon} \quad (3)$$

Where

- y is the n-by-1 response vector for feeling of a subject, and n the number of observations.
- X is the n-by-p fixed effects design matrix, and p the number of all levels of all fixed effects plus the number of covariates. Namely, two levels for gender and three covariates: age, body height, and result from the evaluation algorithm.
- β is the p-by-1 fixed effects vector.
- Z is the n-by-q random effects design matrix, and q the number of all levels of all random effects. Namely, all subject ID levels (28) plus all use case levels (17).
- b is the q-by-1 random effects vector.
- ε is the n-by-1 observation error vector.

6. Conclusions

The described motion capturing method can be applied to objectively record the body motion of a subject and the related joint angles: A subject is filmed while moving in a driver cabin, a Matlab algorithm processes the joints' positions in space and plots all joint angle motions based on time. For the second core part of the method, a concept for an algorithm to evaluate the calculated joint angle motions is proposed. To validate the evaluation algorithms used in the method, a statistical model based on tests with subjects was set up. The skeletal tracking with the Kinect camera is markerless but needs optical accessibility to all joints that shall be measured. Hence, only the joints of the upper body can be captured in a tractor cabin. The camera cannot capture fingers reliably.

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