18.3 Human centric automation: Using marker-less motion capturing for ergonomics analysis and work assistance in manufacturing processes

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Abstract:

Manual labour is still an essential factor for industry. However, work can be physically demanding causing absence through musculoskeletal issues. Moreover, production processes appear to be highly complex causing stress and production errors due to mental fatigue. Methods of human centric automation tackle these problems using automation technology to assist workers. In this paper, we propose marker-less motion capturing to automatically analyse the worker's motion and ergonomics during manufacturing processes. With the information acquired, robots can assist workers to not only meet health demands, but also reduce labour costs and increase the worker's social welfare. Production errors can be reduced by giving situational feedback and guidance based on the worker's motion. We present a first implementation using the Microsoft Kinect® system and propose hypotheses concerning possible social, environmental and economic impacts on semi-automated production, which shall be proven.

Keywords:

Human Centric Automation (HCA); Lifecycle Sustainability Assessment; Sustainability Indicator; Manufacturing Process

1 INTRODUCTION

1.1 Problem Statement

Despite a high degree of automation, assembly and disassembly tasks in industry often depend on manual labour.

Firstly, disassembly and repairing are examples of tasks which have not been planned within a complete product life cycle, so far. The steps to be executed highly vary for each unit to be repaired such that using specialised automatisation devices would result in high costs and a low occupancy rate. Therefore, human workforce is needed for such flexible assembly. Secondly, investing in full automation does not pay off for small lot-sizes or a high number of product variants requiring high flexibility in production [1]. Finally, there are tasks which demand high sensormotoric or cognitive skills which no automated system can fulfil. In brief, human workers are vital due to their flexibility, cost-efficiency and unique skills.

Unfortunately, these tasks can contain situations with high physical load on the worker. According to a German health insurance “AOK” more than one third of the total worker absence in 2009 was caused by musculosceletal complaints or injuries [2]. To reduce physical load, collaborative robots can help. Robots integrated into the workplace can execute physically demanding tasks in the production process on behalf of the human worker or at least simplify them.

Another problem is that complex or monotonous tasks can cause fast mental fatigue resulting in stress at work, reduced performance and production errors. Mental fatigue and stress can be decreased by monitoring systems which guide and supervise workers in their tasks. Employee information systems aggregate all information regarding a work process and present it to the worker in a clear manner. During assembly process, the worker is monitored and guided which leads to a feeling of relief and a reduction of production errors.

We propose Human Centric Automation (HCA) concepts to approach these aforementioned problems. The idea is to use automation technology, in our case robots and optical sensor systems, to assist workers in in their tasks instead of replacing them. We propose to apply them in cases where human workforce is irreplaceable. Recent advances in marker-less motion capturing technology provide the foundations for the solutions presented in this paper.

To ensure that such scenarios improve the workplace area and provide long-term benefit for employers as well as for operators, we analyse HCA by methods of sustainability assessment like the life cycle sustainability assessment.

Therefore, it is needed to elaborate suitable indicators in order to address the pressure and the response on the workers as precise as possible. The enhancement of individual response can be quantified to ensure good working conditions and reduce economic costs (e.g. higher productivity of the worker) as well as environmental burden (e.g. unnecessary waste).

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In this paper, we intend to address these two problems mentioned above with focus on the application as well as the impacts related to the HCA.

1.2 Related Work

Motion Capturing Systems

Motion capturing systems record the subject's movements while performing arbitrary motions. Typical areas of usage are animating characters in animation movies and video games or analysis of movement for sports or medical purposes. In general, there are three types of motion capturing systems: marker-based, marker-less and non-optical motion capturing.

Marker-based systems, such as Vicon motion capture systems, rely on markers attached on predefined locations on the subject. The markers are designed to be easily detectable by a camera system. Using these markers, the software is able to locate particular parts of the body and precisely reconstruct motions. However, the markers can limit the subject’s range of movement. As a result, the recorded motion can differ from the subject’s motion without markers. Another disadvantage is that marker-based systems require a user calibration step where the user has to manually define which marker belongs to which part of the body. This can lead to a long preparation time. Besides, the markers may slip during a recording session decreasing precision.

Marker-less motion capturing systems, in contrast, do not need markers. Example products are OrganicMotion OpenStage® and Microsoft Kinect®. The former addresses professional users - especially in entertainment industry - and works on multiple colour cameras. The latter addresses the consumer market and only relies on a single depth camera. User calibration in marker-less systems only consists of adopting a predefined calibration pose for several seconds. Sometimes, it is even not necessary. On the other hand, marker-based systems generally outperform marker-less approaches regarding precision. Marker-less motion capturing systems also often pose strict limitations on the environment. OpenStage expects the tracking area to be closed by white walls and green or white flooring. Additionally, the space must not be obstructed e.g. by a table [3]. The Kinect requires capturing the subject from the front side. Also, objects which partly occlude the view on the subject often heavily affect precision.

Non-optical motion capturing systems, such as Xsens systems, require the subject to wear inertial or flex sensors. These sensors measure mechanical variables such as acceleration and flexion of particular parts of the body. Cameras and image processing systems are not required making the system insusceptible to obstructed scenes and optically varying environment. The trade-off is that the sensors only measure data relative to the last time step. Absolute positions to locate the subject in space have to be computed from an initial pose. However, measurement errors in each time step can accumulate leading to big absolute errors. Non-optical motion capturing devices also limit the range of movement and require an extensive user calibration step.

Despite, its recent limits, we believe that marker-less motion capturing is becoming increasingly important, since it enables workers to naturally execute their tasks without limitations in movement. As this is a highly active field of research, we expect improvements in terms of precision and robustness in the next years.

Automatic collaboration and assistance in manufacturing

Since the field of automatic collaboration and assistance in manufacturing is broad, we concentrate on the overviews on human-robot cooperation and employee information systems. These two fields are related to the application scenarios presented in this paper.

Krüger et al. [4] gives an extensive overview over recent advances in human-robot cooperation in assembly. The paper also outlines the economic potential of such a technology. There has been a lot of research in this field, especially concerning safety issues. First systems have been developed, but more sophisticated and practically useable solutions are to be expected in the next years. We believe that a lot of potential lies in developing concepts to not only reduce costs (economic dimension), but also improving worker’s health (social dimension).

Concerning employee information systems, several solutions have been released on the market: Bott and Armbruster Engineering present an assembly workplace for worker qualification [5, 6]. The system consists of a computer and a touchscreen which displays the next work step after confirmation of the current one by the worker.

There are also several methods to automatically recognise the current work step making it possible to alert the worker in case of incorrect task execution. The ultrasonic marker-based 3D tracking system AssyControl from Otto Kind AG tracks hand positions during work. Work steps can be identified by analysing hand trajectories. In cooperation with SKODA the multi sensor based “Wearable-Activity-Tracking” has been developed. Multiple sensors are integrated into the worker’s overall. Work step recognition is done by matching sensor profiles to the ones of exemplary work routines [7]. In addition, software has been developed to visualise each step in the assembly process. Process relevant information is shown as text, picture, video or lights attached to fixed positions.

Marker-less motion capturing can improve these solutions, since the hand tracking does not limit freedom of movement. Besides, images of work steps can be captured by a camera which enables to easily create a documentation of the process.

Sustainability Indicators

Sustainability indicators consider all three dimensions of sustainability inclusively and do not focus on the environmental issues alone. Especially environmental indicators have been widely employed for many years, sustainability indicator frameworks are transferred more and more into practice. The first indicators were developed in early 1970 by biologists to describe the health status of an ecosystem. In 1972 the report “Limits to Growth” of the Club of Rome pointed out that continued growth creates stress to the boundaries of our system earth, which can be seen as a first step to think about sustainability [8].

Nevertheless, the most common interpretations of sustainability nowadays are still based on the environmental aspects only. This has its origin partly in political debates starting in the late 1980s and the resulting environmental regulations. Take the aspect climate change as an example: More or less, the whole discussion is on environmental issues and its effect on human kind. Nevertheless, this topic has the potential to include the social and economic dimensions, e.g.include the payment for the changes (how much and by whom) or be aware of the social consequences.

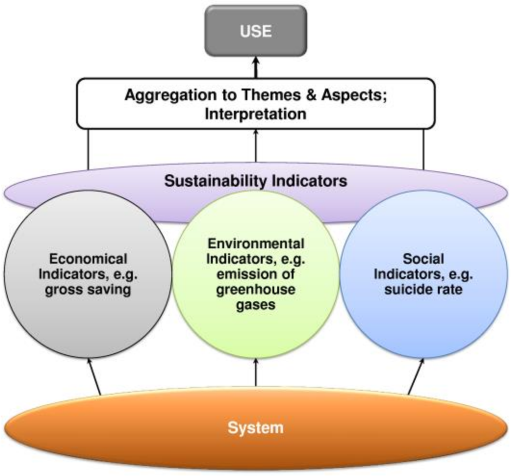

Figure 1: Description of the functionality of sustainability indicators [9].

For a system analysis, e.g. human centric automation the first step is the collection of relevant information (as shown in Figure 1), before the results can be interpreted to make reasonable use in terms of decisions toward a sustainable development.

1.3 Contribution

The contributions to sustainable manufacturing of this study are:

- presentation of application scenarios based on marker-less motion capturing systems to improve work conditions,
- qualitative evaluation of first implementations based on the Kinect system,
- provision of a framework to evaluate the application scenarios concerning environmental, economic and social impacts

2 METHODS

2.1 Motion Capturing System

For our first implementations, we have chosen the Kinect sensor. With its price of about 200 Euros and existing application software ready to be used, the Kinect system enables us to quickly realise a cost-efficient prototype.

The Kinect sensor (see Figure 2) unifies microphones, infrared (IR) camera, colour camera and depth camera. Using the latter, images containing 3D information can be recorded. Each pixel in a depth image denotes the distance from the Kinect device to the nearest object (see Figure 3 right). Depth image generation is done by projecting an IR pattern onto the scene. The distortion of the pattern provides information about the 3D structure of the scene. Since the IR pattern is invisible for colour cameras, there are no scene effects in the colour images.

Figure 2: The Kinect sensor and its components.

There are several software packages which implement marker-less motion capturing algorithms on Kinect depth images. We use the Primesense NiTE™ middleware library from the OpenNI® framework as it offers a platform-independent solution with low computational costs. The software computes absolute joint coordinates given a depth image.

The advantages of the solution are its low costs and that it does not require any user calibration. However, the subject can only be captured from the front perspective. This means in all recordings, the subject has to face the camera device. If the person to be captured turns away, the system may fail to track the motion. To solve this problem, multiple cameras can be used to capture the subject from different perspectives. Unfortunately, it is not possible to use multiple Kinect devices around the subject to always ensure a front view. The projected IR patterns would interfere with each other resulting in even worse depth information quality. Moreover, the system does not work well in case the subject is not completely seen e.g. when a table blocks the view.

In the long run, we plan to implement a motion capturing system based on multiple colour cameras similar to OpenStage to avoid the limitation of perspective.

Figure 3: Left: Colour image of a subject. Right: Depth image and the tracked skeleton. The system draws the back bone and the right arm in red since they represent two examples of ergonomically unfavourable poses.

2.2 Sustainability Indicators and Assessment

Published sets of indicators are taken from e.g. the German Strategy on Sustainability [10, 11], Global Reporting Initiative [12], World Development Indicators [13], International Human Development Indicators [14] or the indicators from the UN Conference of Sustainable Development [15]. They are taken to bridge the manufacturing network with the goal to identify, measure and create a set of suitable indicators for human centric automation.

The indicators are compared to identify duplicates and in order to match them with the demands of the workplace surroundings. A matrix needs to be established with the relevant processes (production, work assistance as well as HCA) in a vertical column and the indicators in a horizontal line. If the process can be measured with the proposed indicator the intersection point will be marked and taken to track the possible development, i.e. the changes on the worker, on the product quality and on the amount of waste.

Afterwards the identified indicators have to be grouped according to the DPSIR framework (introduced and elaborated by the European Environmental Agency [16]. They propose five types of indicators as shown in Figure 4: (i) driving force indicators, (ii) pressure indicators, (iii) state indicators, (iv) impact indicators and (v) response indicators. The driving forces are the forces on an environmental change (e.g. industrial production) by the socio-economic and socio-cultural human activities. The pressures mark the burdens on the environment (e.g. discharges of waste water) by human activities. The state indicators can be used to describe the condition of the environment. The impacts stand for the potential effects of environmental degradation and the response indicators gauge required progress in response of society and government.

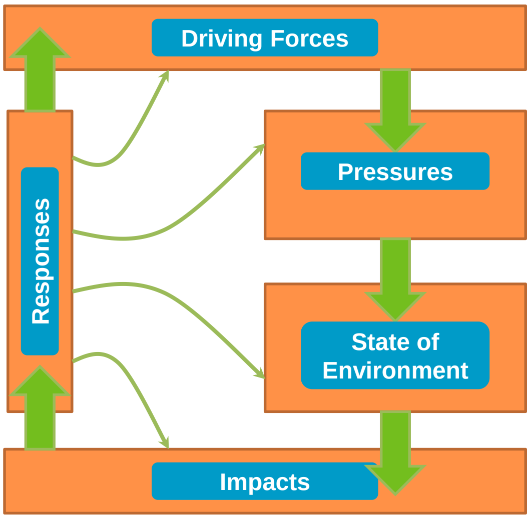

Figure 4: The DPSIR Framework, based on [16]

Finally, according to the implementation of human centric automation indicators are chosen on an exemplary level to show the applicability and to judge the results in terms of supporting decision makers. Hence, a life cycle sustainability assessment can be used as a method to calculate the impact of human centric automation for some quantified indicators.

3 APPLICATIONS

3.1 Ergonomics Assessment

Ergonomics assessment has become a vital component in factory and process planning to ensure health and safety at work. Monitoring tools, such as EAWS [17] have been developed to evaluate processes and workplaces after ergonomic aspects. The overall principle is that load points are assigned for unfavourable physical workload e.g. awkward upper limb or hand poses and handling heavy objects. Finally, the load points are accumulated to determine a final score. These results can be used for risk assessment, planning or redesign of workplaces.

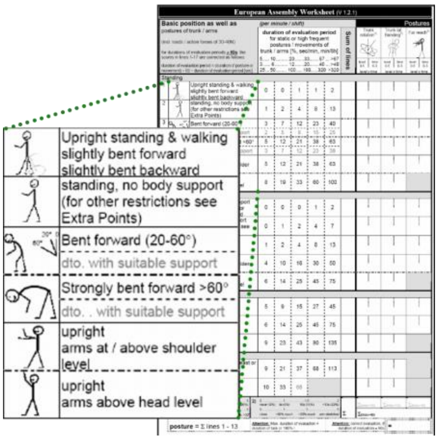

Figure 5: Second page of the EAWS (basic postures).

Automatic ergonomics assessment would provide human robot cooperation systems with essential information.Based on the ergonomics score computed in each situation, the robot is able to decide whether to assist or not and how to assist. Härtel et al. [18] implemented the EAWS using marker-based motion capturing and inertial sensors. We intend to develop a similar system by means of marker-less motion capturing. Our first implementation computes the EAWS basic posture score (see Figure 5) for a process recorded by a Kinect device. We use the 3D limb coordinates provided by the motion capturing system in order to compute joint angles. Using these angles, our system automatically classifies the posture in each image. The overall duration the subject stays in each posture is accumulated in order to acquire detailed statistics. Based on these posture statistics, posture scores from the EAWS sheet can be calculated (see Figure 6).

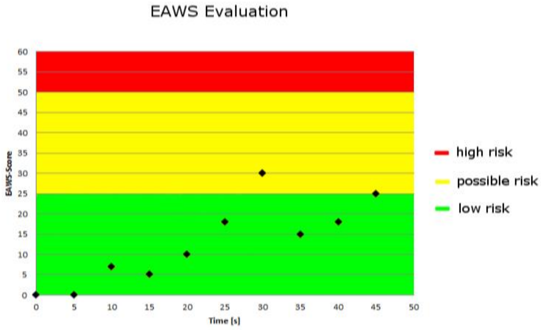

Figure 6: EAWS score of a process computed over time.

3.2 Employee Information Systems

We have developed an employee information system for the guidance of process execution and for worker qualification (see Figure 7). Manual work steps are recognized through marker-less hand tracking with a 3D Time-of-Flight (TOF) camera [19]. The trajectory of the hand and its movement are analysed by MATLAB software.

Over a user interface, work place information is stored in a knowledge base. Based on the content of the workers' hand and its position, work steps like pick, place or the use of objects are automatically recognised. The system creates a work description of the process as well as an analysis based on the method of time measurement UAS[20]. The analysis can be used for documentation as well as basis for system optimisation.

Besides, images from the tracking process are used for visualisation of the task. Based on the work description, text is automatically displayed to describe the work step more in detail and to guide the worker (see Figure 8 left).

We plan to provide the worker with a feedback regarding a incorrect work step and tell what to do instead. With the developed system workers can be passively guided through the display of a work description or actively through the feedback system. This range of options allows a worker qualification related guidance. The worker's stress conditioned by complicated tasks or a low work routine can be reduced. The number of errors can be decreased.

Use cross screw driver 2 times

Description

Use cross screw driver 2 times.

WD File:
alternator_right_1.txt

Figure 7: Our implemented employee information system.

3.3 Robots supporting workers

Using the ergonomics score, especially physically intensive tasks in a process can be identified. Examples are: moving heavy loads or working in awkward postures for a long time.

Robots at workplaces can support the worker. In the first case, the robot could execute the task on behalf of the worker. In the second example, the robot could change working conditions to reduce physical load e.g. by turning and moving the object to be processed such that the worker can work in a "ergonomically better" posture (see Figure 8). For a more cost-efficient configuration, also lifting tables tables with a rotating socket can be used.

The robot has to apply to human robot collaboration safety standards to be able to join work without effecting efficiency or colliding with the worker. Solving this challenge would involve recognising the current work step from observations which should trigger the robot planning assistive actions as soon as the ergonomics score exceeds a threshold.

We plan to tackle this concept of collaboration in subsequent works.

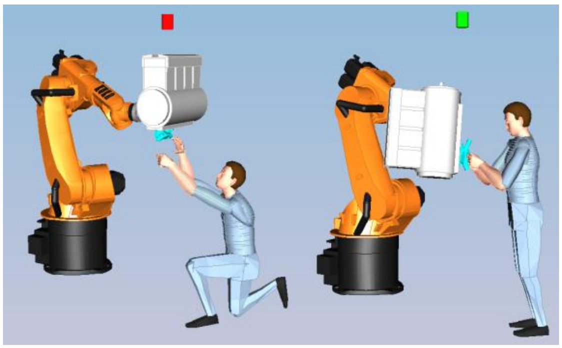

Figure 8: Example of human-robot cooperation. The system automatically detects an unergonomic work pose (left) and makes the robot adjust the object such that the worker can adapt a more ergonomic pose (right).

4 DISCUSSION

In this section, possible environmental, economic and social impacts of the aforementioned application scenarios are discussed. At first, the assumptions were derived for the case of the German industry to address exemplary circumstances which e.g. help to compensate demographic effects in Germany. Later the results shall be transferred to more application, if possible in combination with a change of the regional context.

4.1 Integration of the System into a Workplace

The final system (without robot) consists of a high performance computer and a set of cameras. In order to integrate the system into an existing workplace, the cameras have to be placed in a way that the worker is visible from all perspectives. Afterwards, the camera system has to be calibrated, which means the exact positions of the cameras in space have to be determined. Calibration process will possibly take some minutes and has to be done every time camera positions change.

The system operates in energy saving mode until a subject is detected. In case the worker is seen by the cameras, the system switches to tracking mode activating more computational power. At the moment, we estimate the maximum power consumption of our prototypical system at 1.5kW (1.4kW computer, 100W cameras and display). However, it has to be considered that maximum utilisation is only achieved when the worker is being tracked. Furthermore, we expect the end product to be less power consuming, since the system as such can be optimised in terms of energy usage. It might be even possible that the computer handles the cameras of more than one workplace.

4.2 Possible Environmental Impacts

Clearly, equipment consisting of high performance server and cameras will lead to a reasonable amount of Cos emissions due to higher energy consumption. According to the energy 5.0 specification the total required power consumption results from the operational mode weighting with an off phase of 35% a sleep phase of 10% and an idle phase of 55% [21]. That would mean that the prototype consumes around 20 kWh/d (18.5 kWh/d = server, 1.56 kwh/d camera and display). The electricity consumption results in the emission of 11.3 kg CO_2e. with the German energymix emission factor from the year 2010 [22]. What has not been considered yet is the emissions related with the production of the system as well as with the end of life scenario. Additional studies on that topic will be carried out as soon as the prototype is ready for trial applications to verify the reduction of errors by technical assistance and process education.

4.3 Possible Social Impacts

On the one hand, camera based technology involves dealing with data security and privacy issues. Questions, such as anonymisation of workers and data retention policies have to be discussed. Furthermore, working on camera surveillance can cause feelings of discomfort and anxiety among workers reducing their performance. Finally, robot-human cooperation involves dealing with safety issues. New cooperation systems have to fulfil norms, such as “ISO 10218: Robots for industrial environments – Safety requirements” in order to be allowed in practical use.

On the other hand, worker's health and therefore wellbeing can benefit, since physically demanding tasks can be assisted by robots leaving tasks with low physical load to the human. Assistance systems can also monitor and guide the process helping workers to feel supported during complex tasks and relieving stress. Since we expect an improvement in work performance through assistance, it may be likely that employers now tend to invest more in flexible semi-automation instead of full-automation. Thus, instead of cutting jobs because of automation technology, unemployment rate can be reduced due to improved human performance. Finally, using these systems for qualification can help to improve training. Concerning demographic development in Germany, qualification systems can compensate the loss of experienced trainers due to retirement.

4.4 Possible Economic Impacts

It has to be considered that the introduction of such systems involves reasonable costs. Firstly, it probably costs around 100,000 Euros (excluding robots) to install and operate such a system on an existing workplace. Using 10 professional industry cameras instead of the Kinect device leads to costs of about 30,000 Euros. The processing of such a huge load of image information requires a high performance computer of about 15,000 Euros. The rest of the budget remains for the costs of the ergonomics assessment and robot control software.

In contrast, we believe that these costs will pay off, since higher productivity reduced amount of junk will result in higher margins. Moreover, a lower worker absence rate will reduce the loss for company. In an example calculation, Krüger et al. [4] states that under special circumstances an invest in hybrid workplaces can pay off in less than one month with a reduction of production costs of 58%. If we consider a macroeconomic view, the state will benefit as well, since health expenses can be reduced and more elder people are enabled to work resulting in more taxes as well as reduced social welfare payments.

5 CONCLUSION & OUTLOOK

We have presented solutions including implementations to improve work conditions using methods of human centric automation. Moreover, we provide a first step regarding sustainability assessment of these application scenarios.

Our future works include improving motion capturing technology, developing interaction concepts for human-robot cooperation and installing a trial application in a real factory surrounding.

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REFERENCES

[1] Bley, H., Reinhart, G., Seliger, G., Bernardi, M., and Korne, T., Appropriate human involvement in assembly and disassembly. CIRP Annals-Manufacturing Technology, 2004. **53**(2): p. 487-509.
[2] Badura, B., Schröder, H., Klose, J., and Macco, K., Fehlzeiten-Report 2010: Vielfalt managen & Gesundheit fördern: Potenziale Nutzen Zahlen, Daten, Analysen aus allen Branchen der Wirtschaft. 2010: Springer DE.
[3] Organic Motion, openstage Realtime Markerless Motion Capture. 2012.
[4] Krüger, J., Lien, T.K., and Verl, A., Cooperation of human and machines in assembly lines. CIRP Annals-Manufacturing Technology, 2009. **58**(2): p. 628-646.
[5] Bott, Armbruster Engineering: Gesamtpaket Montagearbeitsplätze mit Werkerführung, handling Heft 1/2. 2012.
[6] Armbruster Engineering, Werkerführung an Montagearbeitsplätzen.

2010.
[7] Stiefmeier, T., Roggen, D., Troster, G., Ogris, G., and Lukowicz, P., Wearable activity tracking in car manufacturing. IEEE Pervasive Computing, 2008. **7**(2): p. 42-42.
[8] Meadows, D.H., Meadows, D.L., Randers, J., and Behrens III, W.W., The Limits to Growth, ed. Rome, C.o. 1972, New York, NY: Universe Books.
[9] Scheumann, R., Fügenschuh, A., Schenker, S., Vierhaus, I., Borndörfer, R., and Finkbeiner, M. Global Manufacturing: How to Use Mathematical Optimisation Methods to Transform to Sustainable Value Creation. in 10th Global Conference on Sustainable Manufacturing. 2012. Istanbul.
[10] Bundesregierung, Perspektiven für Deutschland - Unsere Strategie für eine nachhaltige Entwicklung. 2002: Berlin.
[11] Bundesregierung, Nationale Nachhaltigkeitsstrategie - Fortschrittsbericht 2012. 2012: Berlin.
[12] GRI, Sustainability Reporting Guidelines. 2011, Global Reporting Initiative: Amsterdam, Netherland.
[13] WorldBank, World Development Indicators 2012. 2012, Washington D.C.: World Bank.
[14] HDR, Human Development Report 2013 - The Rise of the South. 2013, United Nations Development Programme: New York City.
[15] UN-DESA, Indicators of Sustainable Development: Guidelines and Methodologies. 2007, United Nations: New York.
[16] EEA, Environmental indicators:Typology and overview in Technical Report No 25/1999. 1999, European Environmental Agency.
[17] Schaub, K., Caragnano, G., Britzke, B., and Bruder, R., The European assembly worksheet. Theoretical Issues in Ergonomics Science, 2012(ahead-of-print).
[18] Härtel, T., Keil, A., Hoffmeyer, A., and Toledo Munoz, B. Capturing and Assessment of Human Motion during Manual Assembly Operation. in First International Symposium on Digital Human Modeling, Conference Proceedings. 14-16 June 2011. Lyon, France.
[19] Postawa, A.B., Kleinsorge, M., Krüger, J., and Seliger, G., Automated image based recognition of manual work steps in the remanufacturing of alternators, in Advances in Sustainable Manufacturing. 2011, Springer. p. 209-214.
[20] Bokranz, R., Landau, K., and e.V, D.M.T.M.V., Produktivitätsmanagement von Arbeitssystemen - MTM Handbuch. 2006, Schäffer-Poeschel Verlag.
[21] European Commission, Commission Decision of 16 June 2009 in regards to the coordination of energy-efficiency labelling programmes for office equipment on the revision of the computer specification in Annex C, part VIII, to the Agreement 2006/1005/EC. 2009, EC: brüssel.
[22] Umweltbundesamt, Entwicklung der spezifischen Kohlendioxid-Emissionen des deutschen Strommix 1990-2010. 2012, FG I 2.5 Energieversorgung und -daten: Dessau-Roßlau.