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Applicability Evaluation of Kinect for EAWS Ergonomic Assessments

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Abstract

With the availability of low cost, markerless motion capture systems, in manufacturing industry more and more companies apply this technology for ergonomics assessments without knowing the overall performance and limitations in advance. This paper presents an applicability evaluation of Kinect sensor's motion capture performance to be used for ergonomics assessments. Even though literature has already presented application papers in manufacturing industry and ergonomic analysis, few papers are giving practical insights on the overall limitations. In particular, the European Assessment Work Sheet (EAWS) is applied as a reference, standardized method. EAWS working postures are systematically carried out in virtual domain and physical domain and are cross-checked with respect the results in EAWS. The results show, that 9 out of 11 working postures can be tracked well and tracking limitations are revealed. For several working postures, passive haptic feedback is required. Therefore, visually low occluding physical mock-ups are proposed.

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Keywords: digital human model; motion capture; ergonomics; assessment; markerless tracking;

1. Introduction

Full body motion capture data is frequently used in manufacturing industry for various use cases such as process verification, visibility checks or buildability assessments. Besides this, more and more ergonomic assessments are carried out using digital human models (DHMs) to virtually audit assembly workplaces and worker postures [1]. In this paper, we briefly presented a hands-on evaluation using a multi-depth camera motion capture system with respect to its applicability for ergonomic assessments. Even though using a multi-depth camera approach, all evaluations hold for single sensor arrangements as well.

Otto et al. presented in multiple publications the technical properties and implementation of a scalable, markerless depth sensor array for full body skeletal tracking [2], [3]. This sensor array allows for 360° rotations of the user's within the tracking frustums and tracking results are optimized on-line, since fusion heuristics are optimizing single sensor's skeletal tracking results. For details on the technical implementations see the abovementioned papers. Both single sensor and multi sensor arrangements rely on the closed-source Kinect SDK provided by Microsoft. The skeletal tracker is working on the principles presented by Shotton et al. [4]. The multi-depth sensor array optimizes the overall fused tracking results, but still relies on the single skeletal tracking results of each sensor. So measuring the overall ability to use the system for ergonomic assessments, a central element of the skeletal tracking is the Kinect V2 SDK motion capture quality.

2. Literature review

Using Kinect v1 and Kinect v2, literature presents many real life application scenarios, case studies [5] in manufacturing industry for ergonomic assessments [6], [7], object tracking and walk path assessments [8].

Even though multiple publications are presenting Kinect v2 as a possibility to be used in ergonomic assessments, none of them have evaluated it with respect to specific working

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postures (see Haggag et al. [9], Geiselhart et al. [6], Bortolini et al. [10], etc.).

Two publications of Plantard et al. are using Kinect for RULA assessments. They first present a pose correction framework [11] with a posture database to optimize occluded skeletal tracking results. Using this system, they achieved "significant improvement of the joint angle accuracy". Subsequently, they use this presented system for online RULA ergonomic assessments in real work conditions [12]. Nevertheless, they do not give practical insights on which movements are feasible and which are not using the vKinect skeletal tracker.

3. Working Postures in Ergonomic Assessments

To avoid musculo-skeletal complaints and disorders of workers, industry companies carry out ergonomic risk assessments. Car manufacturers are doing this for each workplace. Poor ergonomic design of workplaces concerning working postures can be reliably detected using digital human models and therewith even optimized [1], whereas deriving repetitive forces in the virtual domain is still hard to assess. Typical assessment methods for tackling ergonomic workplace assessments are screening tools for physical workload. In automotive industry, plenty of screening tools are applied, most prevalently EAWS by Fraunhofer IAD [13]. Other methods such as RULA, NIOSH, OCRA, NPW, DesignCheck, AAWS are either predecessors or compatible with EAWS. Additionally, international standards for minimum ergonomic requirements are presented in ISO 11226 for postures and ISO 11228 for actions [13]. Those screening tools are often integrated in simulation systems [14], [15]. At the present stage, these simulation tools oftentimes lack in accuracy/parameterization capabilities, which leads to vague assessment results. Additionally, the pre-processing of the specific data is mostly time-consuming, wherefore pen & paper-based assessment methods are generally used.

Nowadays, EAWS is vastly applied in European car manufacturers and widely spread in automotive suppliers [10], [16]. It penalizes unfavorable physical workloads with "load points" and deduces an overall risk assessments. „The EAWS consists of four sections for the evaluation of working postures and movements with low additional physical efforts (< 30-40 N or 3-4 kg respectively), action forces of the whole body or hand finger system, manual materials handling and repetitive loads of the upper limbs." [13]. Working postures are assessed as "static working postures and high frequent movements are estimated" [13]. "Symmetric working postures for standing, sitting, kneeling & crouching and lying & climbing are rated" as well as "asymmetric effects like rotation, lateral bending, and far reach".

4. Study Goal, Setup and Evaluation Method

Using a virtual environment with an animated DHM, an ergonomics expert has to be able to reliably assess the overall process and come to the same conclusions as in the physical domain. This evaluation aims to answer the question whether the Kinect as a standalone and the multi-sensor system presented by Otto et al. [2] is able to deliver assessable results for EAWS working posture assessments. Similarly to the following applicability analysis, Haggag et al. evaluated Kinect v1 for rapid upper limb assessment (RULA) using an automated assessment approach in 2013 [9].

EAWS working postures are evaluated in the following if they can be carried out by using the presented markerless motion capture system. The intended goal is achieved, when the ergonomic expert comes to the same assessment results by visually inspecting all working postures of the animated DHM in the simulation scene.

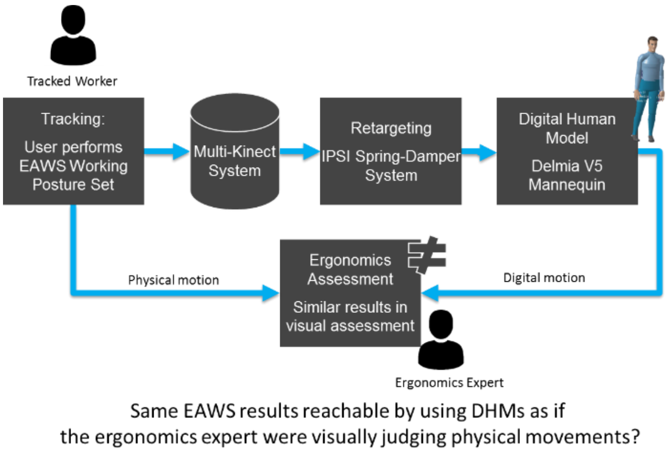

Fig. 1: Block diagram of the EAWS applicability evaluation pipeline

Fig. 1 depicts the system block diagram and pipeline. While being tracked, a worker is performing all EAWS relevant working postures in different symmetric and asymmetric postures. The "Multi-Kinect" tracking system consist of 6 equally distributed sensors and creates real-time motion capture data. Latency is neglectible for these motions. All six sensors are equally distributed and are facing towards the middle of the tracking frustum. There are no optical occlusions in this laboratory setup.

The generated data-stream of skeletal tracking information is packed into the standardized dTrack protocol and then retargeted onto a DHM by using a spring damper system IPSI by Haption. The DHM moves within an empty simulation scene, just consisting of a floor plane and the DHM avatar representation.

4.1. Procedure and participants

For evaluation, 3 participants carry out all EAWS working postures (i.e. standing, sitting, kneeling & crouching and lying) once, having the role of a "tracked worker" (see Fig. 1.). Their motion has been captured and recorded using the multi-depth sensor tracking system and a RGB camera for the physical domain. In the aftermath, an ergonomics expert - working for an automotive OEM company - visually assesses all recorded datasets and tries to fill out the EAWSheet. Both the virtual and physical domain are displayed side-by-side, so that the expert is able to compare both domains. The results indicate, if the expert would come to the same solution, by assessing only the virtual domain. All participants took place on a voluntary basis.

5. Results of Working Posture Analysis Using Markerless Skeletal Tracking

A subjective assessment was conducted considering the abovementioned EAWS working posture levels (i.e. standing, sitting, kneeling & crouching and lying), as well as two non-standardized dynamic postures. The results for each posture level are presented as depicted in Fig. 2.

Body posture	EAWS	Resulting Posture	Lower body	Upper body	Overall
Standing Upright (0° - 20°)			✓	✓	✓
Bent forward (20° - 60°)			✓	✓	✓
Strongly bent forward (> 60°)			!	✓	!
Arms at / above shoulder level			✓	✓	✓

Fig. 2: Evaluation results for working postures "standing"

In general, the working postures "standing upright" and "little bending forward" are applicable for EAWS assessment without any further limitations. Those working postures can be assessed properly by the ergonomics expert. The working posture "strongly bent forward" causes optical occlusions with the legs due to the missing line of sight to the Kinect sensor. Fusion heuristics did not improve the "strongly bent forward" results of a single sensor". However, the overall body posture is still usable, even though the legs are getting jittery. Moreover, the "arms above shoulder" posture as well as combinations with symmetric effects allow a feasible EAWS assessment for all standing postures. In particular, rotation, lateral bending, and far reach are possible. No visible limitations apply for the space within reach.

Body posture	EAWS	Resulting Posture	Lower body	Upper body	Overall
Seated Upright (0-20°)			✓	✓	✓
Seated strongly bent (>20°)			✓	✓	✓
Seated Overhead work			✓	✓	✓

Fig. 3: Evaluation results for working postures "sitting"

Analyzing the gathered results for sitting related body postures it can be denoted that EAWS Working postures "sitting" can be assessed reliably, as long one of the sensors is placed in front (+-30°) of the tracked user. All EAWS "sitting" postures with symmetric and asymmetric combinations are reliably detected and can be used for ergonomic assessments (see Fig. 3)

Body Posture	EAWS	Resulting Posture	Lower body	Upper body	Overall	Remarks
Kneeling & Crouching Upright (0 - 20°)			!	✓	✓	"Crouching" works "Kneeling" does not work properly. The occluded lower legs are tracked as outstretched posture. Nevertheless, the overall body height matches the real scenario, so that the virtual knee touches the virtual floor as can be seen in the pictures on the left.
Kneeling & Crouching Strongly Bent (0 - 20°)			!	✓	✓	
Kneeling & Crouching Overhead Work			!	✓	✓	

Fig. 4: Evaluation results for working postures "crouching"

EAWS Working postures "Kneeling & Crouching" are capturing upper body movements reliably, whereas lower body parts are error-prone. Independently from upper body movements, for working posture "kneeling", lower legs are completely occluded which results in tracking results of outstretched legs penetrating the floor plane. Despite this tracking inaccuracy, the knee and upper leg is on the correct height, so that an overall interpretation is still possible. Same holds for working posture "crouching". If the leg can be seen by a frontal sensor, crouching is working properly. Symmetric and asymmetric upper body combinations are also feasible (see Fig. 5)

Body Posture	EAWS	Resulting Posture	Lower body	Upper body	Overall	Remarks
Lying flat			✗	✗	✗	Data not usable for ergonomic assessments. Too jittery.
Lying >20° upper body (sit-up)			✓	✓	✓	Applicable MoCap results are generated for sit-ups >20°.

Fig. 5: Evaluation results for working postures "lying"

In contrast to the aforementioned body posture types, EAWS working postures "lying" are not working properly with the presented markerless motion capture system. Each sensor in the array was placed at 1.3m height with a horizontal view. Due to the steep viewing angle, lying completely flat on the floor generates only jittery skeletal tracking data, which cannot be applied for ergonomic assessments. If upper body bends up >20° towards a sensor, tracking data can be used again for EAWS (see Fig. 5).

Dynamic movements	Resulting Posture	Lower body	Upper body	Overall	Remarks
360° Rotation		✓	✓	✓	Movement quality is depending on sensor density. For six sensor setup working properly.
Space within reach		✓	✓	✓	No additional limitations induced by tracking technology could be revealed - compared to anthropometric space of reach possibilities.

Fig. 6: Evaluation results for working postures "dynamic postures". 360° rotation only applies for multi-depth camera setup

Given the performed EAWS applicability analysis of the Kinect data, a quantitative measure for static postures can be derived. To gain an insight into the system performance for dynamic postures, two non-standardized dynamic posture evaluations have been carried out. In 360° rotation experiment the tracked user constantly turned around a pole, so that skeletal hand-over between sensors can be evaluated. Tracking data is handed over properly between all six sensors, even the hand sticks on the virtual pole, so that the movement is properly mapped on the DHM using the system presented in [2]. Second, the whole space within reach has been evaluated. No additional limitations compared to physical restrictions have been detected using the skeletal tracking (see Fig. 6).

6. Conclusion and Outlook

All in all, the Kinect v2 skeletal tracker extended with the multi-depth camera tracking algorithms and the retargeting system proved to be suitable to be used for ergonomic assessments in accordance with EAWS.

Overall 9 out of 11 full body postures can be used for assessments, additional postures are not calculated. Three main sources of limitations have been revealed: Optical occlusions cause jittery or unusable motion capture data while strongly bending forward, flat lying on the floor and kneeling on the floor.

In general, optical occlusions are inducing most errors in skeletal tracking results in daily usage of motion capture results. Using large-scale PMUs sometimes occlude tracked users, even though their working posture would be usable.

In future, optically low intrusive physical mock-ups have to be developed, since for complex ergonomic assessments, haptic feedback of the environment is missing. In order to generate a sensation of physical barriers for kneeling sitting and bending and having good tracking performance for markerless tracking, flexible, optically low intrusive physical mock-ups are proposed consisting of aluminum profiles.

Microsoft has announced the Kinect DK in combination with a third generation of Kinect hardware. This study will be updated and the results will be re-evaluated for their validity using the new generation of hardware.

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