Evaluating a Multi Depth Camera System to Consolidate Ergonomic Work in the Education of Caregivers

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Keywords: Nursing Education, Ergonomics, Teaching, Optical Devices, Feedback, Case Studies.

Abstract: Through the demographic change in Western European countries the demand for nurses in elderly care rises. Additionally, constant high physical stresses causing nurses to leave the profession before the retirement age and having a high number of sick leave days. To reduce the physical strain, focus must be set to ergonomically correct work in nursing schools. Currently given technical infrastructure in the schools lacks the capability to provide nursing instructors with analyzable data from simulated care acts. In this work, we present and evaluate the Multi-Kinect-System, our custom developed depth sensor system for recording and analyzing care acts. In a study, 13 students of a nursing school performed a simulated transfer tasks under observation of a nursing instructor and our system. The instructor gives a more in-depth evaluation of the transfer when using the intuitively analyzable data of our system, regarding the feedback length and information content.

1 INTRODUCTION

1.1 Demographic Background

The percentage of elderly people in Germany increases in the next decades. In 2060 there will be 22.3 million people over 65 years, what is 33 % of the German population. In comparison, in the year 2000 they made up only 17 % (Destatis, 2019). This demographic change leads to an increasing demand for care services, severing the situation in the nursing institutions, which are overbooked even today (Kliner et al., 2017; Weißert-Horn et al., 2014). Additionally, the everyday work of the caregivers is accompanied by constant physical and psychological overload. For example, patient transfers are regarded as one of the main factors responsible for back pain for elderly care professionals (Weißert-Horn et al., 2014), leading to a high amount of sick leave, compared to other medical professions (Kliner et al., 2017), see figure 1.

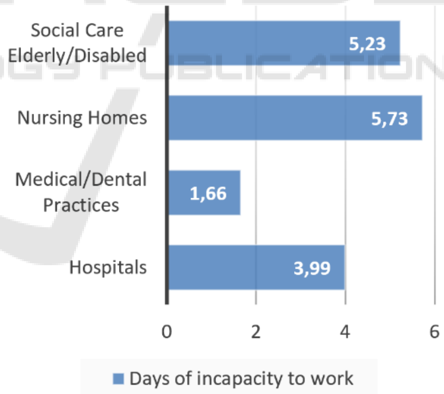

Figure 1: Days of incapacity to work, due to musculoskeletal diseases for employees in medical professions (Kliner et al., 2017).

The impact of physical stress in this understaffed profession is enormous, because a vicious circle forms. High physical loads results in injuries, which are the reason for sick leave, what reduces the staff

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Böhlen, C., Brinkmann, A., Fudickar, S., Hellmers, S. and Hein, A.
Evaluating a Multi Depth Camera System to Consolidate Ergonomic Work in the Education of Caregivers.
DOI: 10.5220/0010186500390046
In *Proceedings of the 14th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2021) - Volume 5: HEALTHINF*, pages 39-46
ISBN: 978-989-758-490-9

and increases the pressure on the remaining staff. Therefore, a reduction of the physical load for caregivers is necessary to prepare the profession for the aging society. A significant reduction of the musculoskeletal stresses of nurses is achievable by an ergonomically correct method of transferring patients (Brinkmann et al., 2020; Jäger et al., 2014). Furthermore, there is an urgent need for training the use of care equipment (Rashidi and Mihailidis, 2013). Even the usage of accessible care aids, like an ant-slip mat during a manual patient transfer can measurably reduce the physical load on the lower back (Jäger et al, 2014).

1.2 Technology-based Approach

Typically, the nursing instructor attends the care acts and gives feedback afterwards, possibly with visual data from one standard camera. However, because of the different poses, nurses are taking during care acts, choosing different view angles is desirable. The usage of an optical system that provides multiple viewpoints and occlusion compensation for the analyzing nursing instructor is desirable. A combination of multiple depth cameras provides these features and to change the point of view in recordings at any time. Additionally, a three-dimensional scene is captured, containing more information than a standard camera image. An in-depth analysis of the care act is possible with such a system. The care instructor and the apprentice nurse have a better insight in the ergonomics of the care transfer and can work together on improvements. However, the technology-based approach with the usage of multiple depth cameras must be evaluated.

1.3 Related Work

Detecting and enhancing the compliance level of health care professionals like nurses with best practices in minimizing job-related back pain is a key research field (Zhao et al., 2016). Studies track specific activities of nurses that might increase the risk of lower back pain injuries, like lifting and pulling (Reichold et al., 2017; Zhao et al., 2016), by videos or instructors by hand. From a technical point of view, the depth camera Microsoft Kinect v2 is evaluated regarding the accuracy of the depth image and the point cloud data (Yang et al., 2015; Fifelski et al., 2018; Fankhauser et al., 2015). The LiveScan3D by Kowalski et. al. (Kowalski et al., 2015) is a system that combines the depth images of multiple Kinects V2 to display colored point clouds. Markers and the Iterative Closest Point (ICP) algorithm (Besl and McKay, 1992) are used to combine the generated point clouds. It is shown that this system can be used to scan a human head precisely enough to create 3D printed figurines. The idea of training nurses in specific scenarios or simulation-based is a common and evaluated practice, for example in resuscitation (Roh et al., 2013). Furthermore, the application of technology in the education is not limited to acquire data or providing scenarios. Approaches to analyze training with algorithms, processing the gathered data are possible (Reichold et al., 2017; Lins et al., 2018; Lins et al., 2019). In order to assure a more distinct evaluation of physical demanding nursing tasks, we propose a System for multiview recording, with the aim to provide high quality data for the nursing instructor. As most algorithms are just estimating positions of bodies or poses in the observed scenes, the analysis of a care expert is necessary anyway. The Multi-Kinect-System in this work provides higher frame rates and is capable to process a larger area of interest, compared to the mentioned approaches.

2 MATERIALS AND METHODS

2.1 Multi-Kinect-System

For the pose and movement analysis an optical system provides the necessary data. Here the combination of four Microsoft Kinect v2 depth cameras is used. In three-dimensional, colored point clouds it is possible to view the scene from indefinite adjustable view angles. Because the point clouds are merely three-dimensional objects, they can be rotated or translated during visualization in real time or offline. This is beneficial while observing care acts like transfers, due to the possibility to see poses and movements from different sides. A depth camera can be occluded by obstacles or humans in the scene. A combination of several depth cameras can compensate the occlusion. Additionally, the point clouds of multiple depth cameras can be combined to a single point cloud. This increases the density of the data and covers scenes from different sides. The depth cameras are situated around the bed and are focusing the center of the bed. All four cameras are installed on tripods at 1.8 m and cover an area of approximately 2 m * 2m. They tilted towards the ground at 45 degrees. Research by Fankhauser et. Al (Fankhauser et al., 2015) indicates that the best distance from the point of interest to the camera is around 0.8 to 1.2 meters. Also, the depth accuracy deteriorates in the corners of the depth image (Fankhauser et al., 2015). Therefore, the placement of the cameras needs to follow these findings. Each Kinect v2 is connected to a mini pc via USB 3.0 that runs Windows 10. The Kinect v2 Software Development Kit (SDK) only runs on Windows machines. Because the whole room network is ROS-based the minicomputers are communicating to a master computer running Ubuntu 16.04 and ROS via private Ethernet connections. A server network PCI card must be installed to handle the traffic. Contrary to standard RGB cameras, the Microsoft Kinect v2 is able of acquiring a depth image alongside with color information. Although it is also possible to obtain other data streams like infrared and a coarse body estimation, we focus on depth and color information. The depth information is obtained at a rate of 30 Hz with 512 * 424 pixel, while the color image features 1920 * 1080 Pixel at 30 Hz. The Kinect v2 SDK provides tools to map the color information to the depth image. In short, all color pixels are discarded for regions which are not in the depth image. This reduces the resolution of the color image. The depth data must be processed with a static Look-up-Table (LUT), internal saved by each camera, in order to calculate point clouds. This is necessary because each Kinect v2 has slightly different lens distortion parameters. The mapped color image stream and the point cloud can be combined to a colored point cloud on the master computer, see figure 2. The colored point clouds are displayed for the analysis to the nursing instructor.

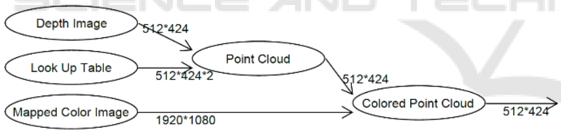

Figure 2: The generation of point clouds. First, the depth image and LUT are combined to a colorless point cloud. Afterwards the color information is added. The resulting colored point cloud of 512 * 424 with 4 bytes each point must be computed 30 times per second per camera.

Another step, that must be done before using the systems, is to register the four depth cameras to each other. The 3D registration can be done in different ways with printed patterns or objects of a special shape. We use a 15 cm radius Styrofoam sphere. The sphere is placed on at least three different spots in the view of all cameras. This allows to calculate the relative position from one camera to another. In the visualization of the four aligned point clouds, the user can adjust the viewpoint. Additionally, we implemented a player that can be used like a standard video player for point clouds, see figure 3. Even in the recordings and when the recorded point cloud is paused, it is still possible to change the point of view at any time.

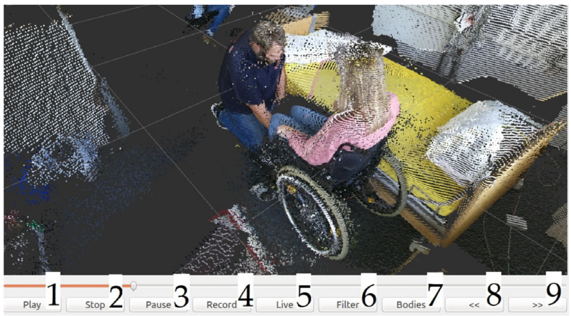

Figure 3: The point cloud player window. Its pixelated appearance is caused by the depth camera resolution of 512 * 424. It is possible to play (1), stop (2), pause (3), rewind (8), forward (9) or record (4) point clouds. The live button (5) switches from recording to live data. To reduce the size of the recorded files it is possible to apply voxel grid and statistical outlier filters (6). The coarse body estimation can be turned on, too (7).

2.2 Case Study

The study "stark" (Studie zur Transferanalyse rückenschonender Pflegekonzepte) (Study for Transfer Analysis of back-sparing Care Concepts) is designed to compare traditional with multiview 3D imaging feedback rounds. The study is approved by the ethical board of the Carl von Ossietzky University Oldenburg (Drs.EK/2019/004).The research question is whether it is possible to identify the impact of the Multi-Kinect-System on the second feedback round. There are 13 study participants involved. To evaluate a transfer regarding the Kinesthetic care conception (Maietta and Hatch, 2011) and ergonomic ways of work, typically, the nursing instructor supervises the transfer and gives feedback afterwards. This procedure can be enhanced and digitized through our complex Multi-Kinect-System. To evaluate our Multi-Kinect-System in the field, audio is recorded. The recordings are done in a case study where a nursing instructor uses the system while educating nurses. This study compares feedback with and without the usage of the Multi-Kinect-System. A nursing instructor articulates which function of the Multi-Kinect-System point cloud player should be used, i.e. what the instructor wants to see. The indirect usage reduces the influence of the usability of the system. These commands are fulfilled by the study organizer on the recording computer. The recordings are containing key words, indicating the use of the Multi-Kinect-System. The observed keywords are "stop", "rewind", "forward", "turn view angle" and words with a similar semantic. Furthermore, the time of the feedback rounds is compared, and the criticized aspects are tracked. These aspects are body balance, knee and lunge positioning, back, stand, usage of caretakers movement resources and the whole movement sequence. The transfer from a care bed to a wheelchair is the observed task, the study participant must fulfill. The patient is a 28-year-old woman weighting 63 kg and already sitting on the bed's edge. The patient is acting like a movement impaired elderly person with abdominal stability while standing. To accomplish the transfer correctly, the participant must use the movement resources of the patient, the care equipment and the learned knowledge how to transfer movement impaired people. Because the participants are differing in height, strength and expertise, there is not one pattern solution. Nevertheless, the participant should choose the right grips and poses to apply forces according to the nature of the patient's body. This study relies on nurses of the Evangelische Altenpflegeschule e.V. Oldenburg nursing school. Although the participants are still in the school courses, they are working in nursing homes or similar institutions as caregivers. Some of them are in the courses for further education to obtain a higher qualification in the profession. Therefore, they have a lot of practical experience and are already instructed how to use their body and the care equipment correctly. Nevertheless, they are making mistakes during the transfer task, too.

Figure 4: The study setup. A wheelchair is situated beneath a care bed. The transfer is carried out on the force measurement plate in front of the bed.

Overall, 13 participants performed the transfer task. The age of the 10 women and 3 men ranges from 18 to 55 years. There are no participants with physical restrictions. The participants are entering the study location and are prepared for the transfer task. In addition to the examined Multi-Kinect-System, a few other sensors are used, observing the performance of the participant for other research interests. These sensors are an electromyograph, a sensor suit (Motion Workshop, 2020) and a ground reaction force plate (AMTI, 2016). None of the used sensors are impairing the movement of the participant. However, this work focuses on the evaluation of the Multi-Kinect-System. The wheelchair is placed on the right side besides the care bed. Because the force measurement plate elevating the participant 12 cm over the ground, the wheelchair is always elevated on a socket, see figure 4. The nursing instructor supervises each transfer by visual inspection, but without the data of the Multi-Kinect-System at first. This feedback is recorded. Afterwards the same transfer is examined again, but this time with the Multi-Kinect-System. To see the data, the participant and the instructor are gathering around the recording computer. This second feedback round is recorded again. The goal is to find and evaluate the differences between the both feedback rounds. The comparison is essential to derive how the sensor system extends the perception of the nursing instructor.

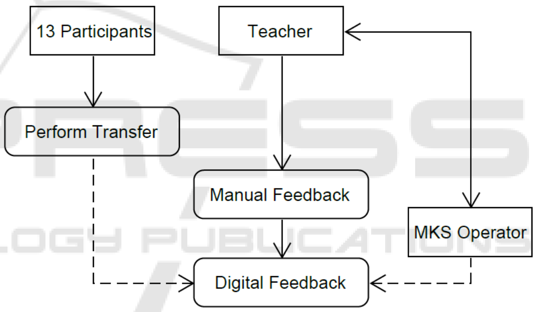

Figure 5: The study procedure. Direct dependencies are marked with solid lines and indirect ones with dotted lines. The Multi-Kinect-System operator (MKS Operator) provides the digital data and is therefore indirectly involved in the digital feedback. Additionally, the nurse can review the own performance in the digital feedback round and therefore understand and react to critics.

Observing the own performance in the scenario might be educational for the nurse. The study organizers are just involved as passive participants (DeWalt and DeWalt, 2011). The three-dimensional data is presented to the nurse and the nursing instructor. A study organizer is operating the system, following their commands by changing the zoom or the viewpoint and pausing, rewinding or forwarding the recorded data. Figure 5 depicts the procedure. The resulting data set, which must be analyzed, consists of two audio recordings per study participant.

3 RESULTS

The data gathered during the feedback rounds with and without the Multi-Kinect-System is audio data. Therefore, the task is to designate features, which are differing in both feedback rounds. The following features are relevant: the duration, special keywords, which are indicating the use of the Multi-Kinect-System and the proposed improvements. Each of the 13 study participants is represented by a three-digit number. Note, that the order of the numbers in the following graphs and tables is not the order in which they performed the transfer task.

3.1 Duration of the Feedback round

Based on the point cloud recordings, the feedback round with the use of the Multi-Kinect-System must take at least longer than the feedback without the system to reason the usefulness of the system. We assume that a higher duration of a feedback round indicates a possible presence of additional information. However, the information of the both feedback rounds is examined later in addition to the plain duration here. Table 1 compares the duration of the audio recording with and without the Multi-Kinect-System. Figure 6 depicts these differences in the duration.

Table 1: The duration of the analog (TA) and digital (TD) feedback rounds for each study participant (SP) in minutes. TA average is 0:59, TD average is 2:16.

SP	**142**	**243**	**424**	**471**	**483**	**107**	**280**	**303**	**350**	**366**	**315**	**437**	**473**
TA	0:57	0:43	0:59	0:36	1:00	1:09	1:41	1:29	0:38	1:10	0:38	1:01	0:46
TD	4:06	2:58	2:01	2:09	1:55	1:28	2:07	3:37	2:43	1:27	1:07	2:33	1:20

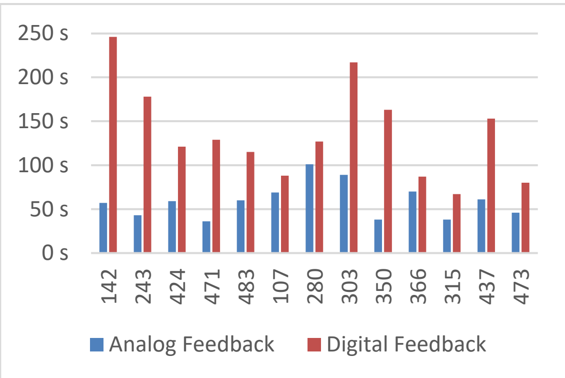

Figure 6: The different time duration of the feedback rounds in seconds for each Study participant.

3.2 Keywords in the Feedback round with the Multi-Kinect-System

The audio recordings are indicating the use of the Multi-Kinect-System. There are keywords like "stop", "rewind", "forward", "turn view angle" and words with a similar semantic, which can be quantified. Table 2 shows the occurrences of the keywords for each study participants, who are represented by a three-digit number.

Table 2: The occurrences of keywords (#K) for each study participant (SP).

SP	**142**	**243**	**424**	**471**	**483**	**107**	**280**	**303**	**350**	**366**	**315**	**437**	**473**
#K	3	3	3	2	1	5	1	1	2	1	1	2	1

3.3 Amount of Criticized Aspects

The overall aim is still to improve the caregivers movements, respecting Kinaesthetics (Maietta and Hatch, 2011) care conception and ergonomic approaches. Therefore, it is necessary to compare the improvements and the critic, the nursing instructor suggests in the both feedback rounds. The six aspects, which are the most important for a healthy transfer regarding the caregiver, are examined. These aspects were chosen according to the nursing instructor:

- body balance (BAL)
- knee and lunge positioning (LNG)
- usage and form of the back (BAK)
- stand on the ground (STD)
- usage of the caretakers movement resources (RES)
- movement sequence (MVM)

Body balance is important during the transfer to control the weight of the caretakers at all time. To shift the load from the back to the lower extremities a lunge position alongside with the right knee angle is desirable. Both, the back and the neck should be stretched, so that the lifting is not performed with a bent or twisted spine. The most relevant body part is the back, as the loss of working time is caused by back pain. This is also related to the positioning of the feet to get a stable stand. A too narrow stand reduces the stability. Because all transfers should take the caretakers movement resources into account, to avoid unnecessary loads, this aspect is mentioned during the feedback rounds. The right movement patterns and sequences should avoid unfavorable activities like the torsion of the spine. In the first feedback round, the audio is recorded, and the criticized aspects can be counted. Afterwards the transfer is observed using the Multi-Kinect-System. The following table 3 presents the occurrences of the mentioned critics for each study participant (SP) for both feedback rounds.

Table 3: The criticized aspects in the analog and digital feedback. The values are separated by a slash. BAL: body balance, LNG: knee and lunge positioning, BAK: back, STD: stand, RES: usage of the caretaker's movement resources, MVM: movement sequence. Average of SUM (sum) of analog feedback round is 2.31 (overall 30) and average of digital feedback round is SUM is 3.38 (overall 44). SP is the study participant.

SP	BAL	LNG	BAK	STD	RES	MVM	SUM
142	1/1	0/2	0/1	1/2	1/0	1/2	4/8
243	0/1	0/0	0/0	0/0	0/2	0/1	0/4
424	0/1	1/0	1/1	0/0	1/1	0/1	3/4
471	1/1	1/0	0/2	0/0	1/0	0/0	3/3
483	1/1	0/0	0/0	0/0	1/1	0/0	2/2
107	1/1	0/1	0/1	0/0	0/0	1/0	2/3
280	2/2	2/2	1/3	0/1	0/0	0/1	5/9
303	0/0	1/0	1/1	0/1	0/0	0/0	2/2
350	0/0	1/0	1/2	0/1	0/0	1/0	3/3
366	0/0	1/0	0/0	0/0	0/0	1/0	2/0
315	0/0	0/0	0/0	0/	0/1	0/0	0/1
437	1/1	1/1	0/1	0/0	1/1	0/0	3/4
473	0/1	1/0	0/0	0/0	0/0	0/0	1/1

3.4 Information Content

The plain duration of the feedback solely is no prove regarding the information content. However, when using the feedback duration as an indicator for a more in-depth debriefing, while also considering the amount of criticized aspects in the transfer, denser information can be assumed while using the Multi-Kinect-System. The sum of the criticized aspects is 2.31 with analog feedback and 3.39 with digital feedback on average, while the average analog feedback time is 59 seconds and digital is 2 minutes and 16 seconds. For example, for the study participant 142, the feedback time increased by 3 minutes and 9 seconds between analog feedback and the feedback with the Multi-Kinect-System. Dividing the average feedback time by the average amount of criticized aspects, the result is 25 seconds per criticized aspect for analog feedback and 40 seconds per criticized aspect for digital. This can either indicate that less time per mentioned aspect is needed in the analog feedback or the digital feedback round is more in depth through the possibilities of the Multi-Kinect-System. However, the amount of mentioned or criticized aspects should always have more priority than duration concerns. Note that the indirect usage of the Multi-Kinect-System also consumes a one-digit number of seconds per participant.

3.5 Discovery of Aspects in the Digital Feedback

Looking into the data of the point cloud player for study participant 107, additional aspects regarding the lunge positioning and one additional aspect regarding the usage of the back were discovered by the nursing instructor. The usage of the Multi-Kinect-System makes additional aspects visible in this and other cases. Because the analog feedback is always the first to take place, it is more likely, that issues, discussed in the analog feedback, are not mentioned again in the digital feedback round. Indeed, the amount of criticized aspects in table 3, is higher in some classes for some of the study participants, than in table 4. However, the overall count of criticized aspects increases significantly between analog and digital feedback rounds.

4 DISCUSSION

The different findings in the feedback rounds are significant and must be researched further. Additionally, the care instructors need training to use the proposed software on their own, without further help. A possible impact on the overall usefulness of the system and the benefit for the nursing instructor and the student seems to be the usability. Although there are no complaints about the data quality of the depth data, it is planned to improve the technical parameters of our Multi-Kinect-System. Improvable aspects are resolution, accuracy and usability with the use of new hard and software. Furthermore, additional studies must be established with more participants and specialized Kinaesthetics (Maietta and Hatch, 2011) trainers. More education facilities should be involved in testing our system in their education program. This helps to install this system in the everyday education of nurses in elderly care, probably increasing their competences and helping nursing instructor to detect unfavorable poses and movements in the education process earlier. Additionally, the usage of automatic pose evaluation algorithms (Stoffert, 1985) is planned to support the instructor's feedback. More in-depth analysis of characteristics of unfavorable poses could also lead to a better understanding why they are common. A future goal is to integrate our system as an inherent part in the education of nurses.

5 CONCLUSIONS

A case study was executed for the evaluation of our Multi-Kinect-System to quantify the benefits of technology-based education enhancements. In this first approach, we use participating observation and audio recordings during two types of feedback rounds after a care scenario, completed by the study participants. One feedback is given by a nursing instructor without advanced visual 3D recording data and one feedback is given with this data. These feedback rounds are differing significantly in various parameters. We identified meaningful features, which are indicating the usefulness of our system in the education of nurses in elderly care.

ACKNOWLEDGEMENTS

This work is carried out in the research project ITAGAP, funding number: 02L14A240 of the *Bundesministerium für Bildung und Forschung* – BMBF (German Federal Ministry for Education and Research) at the Evangelische Altenpflegeschule e.V. Oldenburg (Evangelical Nursing School).

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