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Assessing the Accuracy of the Azure Kinect for Telerehabilitation After Breast Cancer Surgery

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Abstract. Background: Rehabilitation plays a key role in the recovery of upper extremity function after breast cancer surgery. Motion capture (mocap) systems for serious gaming have shown the potential to enable home-based rehabilitation, but clinical accuracy needs to be examined. Objectives: Validation of markerless mocap systems for telerehabilitation after breast cancer surgical intervention. Methods: The accuracy of the markerless mocap device Azure Kinect in detecting compensatory movements and postural disturbances has been compared to a gold standard Optitrack system in five volunteers. Subsequently, a serious game for mocap-based shoulder exercises has been developed and integrated into a telerehabilitation platform. Results: The Azure Kinect shows good reliability for scapular elevation (ICC >0.80; MAE <2.1 cm) and trunk tilt (ICC=0.88; MAE=5°), moderate reliability for rounded shoulders (ICC=0.51; MAE=2.6cm) and poor reliability for kyphosis angle (ICC=0.22; MAE=18°). Conclusion: The Azure Kinect provides reasonable performance for shoulder rehabilitation. The proposed telerehabilitation platform has been tested by rehabilitation specialists and received positive feedback.

Keywords. Telerehabilitation, Exergaming, Exercise Therapy, Motion Capture, Breast Neoplasms.

1. Introduction

Breast cancer is one of the most prevalent malignancies, affecting approximately 1 in 8 women at least once in their lifetime [1]. Surgical interventions such as mastectomy and lumpectomy are widely accepted as effective treatment options for breast cancer, with a reported five-year relative survival rate of 90% [1]. However, following surgery, patients often experience various symptoms in the shoulder proximal to the affected breast, including pain, swelling, and limited range of motion in arm elevation, which can become chronic health issues if not treated [2]. Rehabilitation, including functional upper limb exercises, can improve muscle strength, reduce postoperative complications, and improve function and quality of life of the affected shoulder. Furthermore, rehabilitation exercise has been shown to release β-endorphins, which can alleviate pain, improve sleep, and reduce fatigue [3].

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A major challenge in recovery from breast cancer surgery is the restricted range of motion (ROM) and inflexibility of the affected shoulder, which can lead to the development of compensatory patterns or postural abnormalities. These compensations may provide temporary relief or support but ultimately hinder the recovery process and may lead to further injury [4]. Therefore, it is crucial for rehabilitation programs to identify and correct these compensatory patterns in order to achieve optimal recovery and function of the affected limb.

Recently, the use of motion capture (mocap) systems in rehabilitation has increased significantly [5]. In particular, RGB-D camera systems have received considerable attention due to their cost-effectiveness and ease of use, despite their limited accuracy compared to other solutions. The performance of the Microsoft Azure Kinect DK [6], a prominent RGB-D system, has been extensively investigated and found to be suitable for various clinical applications [7]. However, its ability to detect shoulder compensation and postural disorders has yet to be determined. Nevertheless, the device has already demonstrated its usefulness for serious gaming, a technology that has been shown to improve therapy adherence, recovery, and ultimately patient satisfaction [8]. Furthermore, it opens up the possibility for patients to perform rehabilitation at home while being constantly monitored by clinicians through a telerehabilitation platform [9].

In this context, this study aims to explore the potential of markerless mocap systems in providing personalized home-based rehabilitation after breast cancer surgery. To achieve this goal, an evaluation of the accuracy of the Azure Kinect in detecting compensatory patterns and postural abnormalities associated with shoulder dysfunction has been conducted. Then, based on these results, a serious game for shoulder rehabilitation has been developed. Finally, the exergame has been integrated into a telerehabilitation platform that allows patients to follow personalized digital rehabilitation programs at home.

2. Methods

The proposed method starts from the identification of a set of compensatory patterns and postural imbalances that typically affect breast cancer surgery patients. Through a review of the scientific literature and several meetings with the medical staff of a rehabilitation center, four criticalities have been identified.

- **Kyphosis**, a pathological accentuation of the curvature that characterizes the thoracic section of the spine. Typically, an angle of more than 45 degrees is considered excessive.
- **Rounded shoulders**, characterized by a resting shoulder position that has moved forward from the body's ideal alignment.
- **Back tilt compensation**, an instinctive action taken when raising an arm with mobility restrictions.
- **Scapular elevation**, the raising of the shoulder when moving the limb. Reduced ROM can lead to excessive elevation.

Thereafter, a software program for the Azure Kinect has been developed to measure each criticality. The kyphosis angle, back tilt angle, and shoulder blade elevation have been calculated directly over the virtual skeleton using Euclidean geometry. However, detecting rounded shoulders using a single RGB-D sensor can present a challenge due to the relatively small forward inclination of the joints, even in severe cases. To address this issue, shoulder distance has been employed as a proxy metric to monitor posture variation during both exercise execution and rehabilitation sessions.

Following, the accuracy of the markerless sensor in assessing the aforementioned criticalities has been quantified by comparison with Optitrack, a high-precision marker-based system typically considered a gold standard for mocap. To this end, five healthy young adults have been simultaneously tracked by both systems while performing a defined set of movements and the measurements from both systems have been compared using statistical analysis. Volunteers have been instructed to start from a neutral standing position and then to: (i) raise and lower their left and (ii) right shoulder, (iii) round their shoulders by pushing them forward and backward, (iv) tilt back their trunk, and (v) increase the angle of kyphosis by flexing the upper back. Each operation has been iterated five times. The reference value for kyphosis has been computed as the angle between markers placed on the apex of the thoracic cage and the C7 and T11 vertebrae, according to Lee et al. [10]. Scapular elevation has been measured through markers placed over the acromion. The distance between these markers has been exploited to measure shoulder roundness. For the trunk tilt angle, markers have been attached to the C7 and L5 vertebrae. The position of the RGB-D sensor is 140 cm in height and 130 cm far from the tracked subject. The agreement between the Kinect Azure and the gold standard has been measured using the intraclass correlation coefficient ICC(A, 1) (two-way mixed, single measures, absolute agreement) and the results have been interpreted according to the guidelines of Koo and Li [11].

Subsequently, a serious game for recovery has been developed in Unity. The focus is on performing an anterior-posterior flexion of the arms while being constantly monitored by the mocap system. If compensatory movements are detected, a warning is displayed to the patient. Although the injury typically affects only one limb, patients are instructed to perform the exercise with both arms alternately, thus benefiting from the contralateral effect of training [12] and preventing muscle imbalances. In addition, the range of motion can be adjusted to vary the difficulty of the exercise. To increase patient motivation and engagement, elements such as audio, timing, and scoring have been incorporated into the game.

Finally, a telerehabilitation platform has been developed to facilitate the planning and execution of rehabilitation. It consists of four main modules: (i) the serious game; (ii) an Android app designed to allow physicians to check patients' improvements and schedule work sessions; (iii) an Android app that allows patients to keep track of their progress and be notified when scheduled sessions are due; (iv) a backend server written in Loopback.

3. Results

Measurement performances of Azure Kinect

Comparison with the Optitrack system has shown that the Azure Kinect has good reliability for measuring left scapular elevation (ICC=0.80), right scapular elevation (ICC=0.88), and trunk tilt (ICC=0.88); moderate reliability for shoulder distance (ICC=0.51); poor reliability for kyphosis angle (ICC=0.22) (Table 1). The mean absolute error (MAE) for scapular elevation has been found to be no more than 2.0 cm, with a slight difference between the right and left shoulder. A similar value has been found for shoulder distance measurement MAE (2.6 cm). The trunk tilt MAE is 5°, while the kyphosis angle MAE reaches 18°. The latter inaccuracy can be explained by the fact that, according to the literature, the kyphosis angle should be calculated between C7, T-apex and T11, but no perfectly equivalent landmarks are available on the Azure Kinect skeleton.

Table 1. Summary of measurement errors of the Azure Kinect. Asterisks denote a significant difference ($p < 0.05$). Abbreviations: ICC (intraclass correlation coefficient); MAE (mean absolute error).

	ICC(A, 1)	MAE	Median error	T-test p-value	Shapiro-Wilk p-value
Left scapula elevation	0.8005	12.5 mm	10.9 mm	(*) < 0.0001	0.2581
Right scapula elevation	0.8770	20.1 mm	19.3 mm	(*) < 0.0001	0.2490
Shoulder distance	0.5119	25.8 mm	-26.0 mm	(*) < 0.0001	0.1226
Trunk tilt	0.8809	5.1°	4.6°	(*) 0.0005	(*) 0.0045
Kyphosis angle	0.2222	17.9°	18.8°	(*) < 0.0001	0.1904

In general, measurement error can be expressed as the sum of systematic error (bias) and stochastic error [13]. Ideally, the bias should be zero and the stochastic component should be normally distributed with as little variance as possible. The one-sample t-test shows that all parameter errors present an average value significantly different from zero, thus indicating the presence of a systematic error. The median values found indicate that Azure Kinect overestimates the shoulder distance variation, while underestimating all the other quantities. According to the Shapiro-Wilk test, only the trunk tilt error distribution is significantly non-normally distributed, as shown in Figure 1.

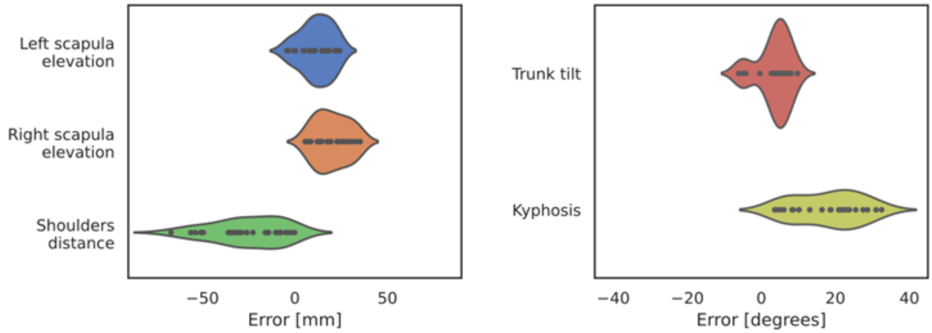

Figure 1. Violin plot of the measurement errors of the Azure Kinect. Dark dots represent individual observations, while shades are a kernel density estimation of the underlying distribution.

Tele-rehabilitation platform

The software solution consists of a serious game and two mobile applications for patients and medical personnel. All the data in the system is exchanged through a web server software architecture. The physician has the ability to use an Android application to manage patients' sessions, monitor the results, and give feedback. The patients are also provided with an Android application that allows them to check the availability of a session and the feedback from the medical staff.

Each patient is provided with a serious game coupled with the Azure Kinect device, through which they are able to perform the rehabilitation session. The virtual environment of the serious game is a familiar kitchen: the patient already knows the movement to be performed and it is therefore easier to have a correct execution. In particular, the patient has to pick up some objects from the shelves of a virtual kitchen, as shown in Figure 2.

There are two different possible levels for the serious game. In this way, by changing the height of the shelves and therefore of the elements on them, the patient is forced to perform the same movement with two different maximum ROMs: in the first level, the easiest, the elements are accessible even if the shoulder stiffness is severe and the patient has not yet regained a full ROM; in the second case, the movement requires a greater range and is therefore suitable only for patients with an advanced level of rehabilitation.

The virtual avatar positioned in front of the shelves mirrors the patient's movement, providing a direct view of the movement as the patient performs it. The level of transparency is adequate both to see what is displayed on the shelves and for the patient to monitor his own movement. Each time the patient completes a session, the doctor receives a notification from the application, and the same happens when the medical staff adds a new session for the patient.

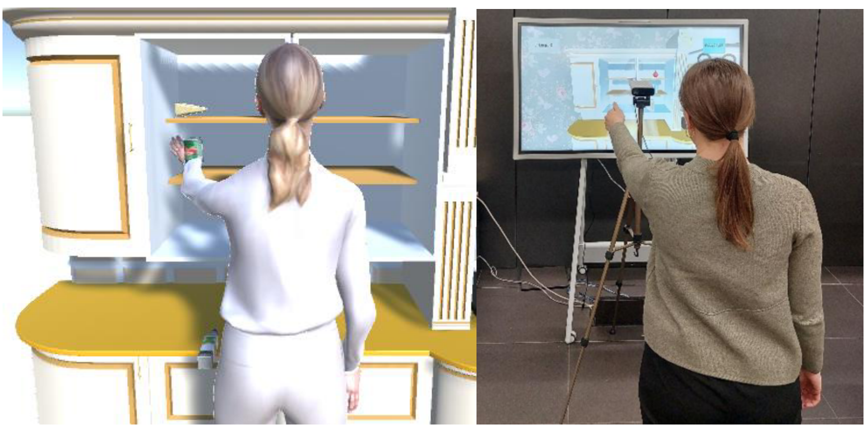

Figure 2. A volunteer uses the developed serious game to perform ad-hoc scheduled rehabilitation exercises.

4. Conclusions

In this study, the utilization of markerless mocap systems in the telerehabilitation process following breast cancer surgery has been investigated. Compared to the current scientific literature [14, 15], the main novelty of this study is the exploration of the accuracy of the Azure Kinect in detecting compensatory patterns and postural disturbances associated with shoulder injuries. The results of this study suggest that the sensor measurements are affected by a systematic error. However, it has been found that the markerless system provides measures of scapular elevation, shoulder distance, and trunk backward tilt with moderate to good reliability, which can be considered acceptable for most rehabilitation purposes. On the other hand, measurements of kyphosis angle have been found to have poor reliability. Furthermore, the results of this analysis support the development of a digital platform for shoulder rehabilitation. The platform includes a serious game that guides patients in performing appropriate exercises while monitoring for unwanted compensation using an Azure Kinect. Patient performance is recorded and made available to physicians via a web interface, as well as the ability to schedule rehabilitation sessions tailored to the individual needs of each patient. Additionally, a smartphone application that allows patients to check their personalized rehabilitation plan and progression has been developed, promoting adherence to therapy. Initial feedback on the platform has been received from clinicians, who appreciate the ability to remotely monitor patient progress and adjust prescriptions accordingly. Future developments include conducting a usability study of the digital platform on a panel of volunteers.

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References

[1] American Cancer Society, *Breast cancer facts & figures 2019–2020*, 2019.
[2] M. Torres Lacomba, O. Mayoral del Moral, J.L. Coperias Zazo, M.J. Yuste Sánchez, J.-C. Ferrandez, and Á. Zapico Goñi, Axillary web syndrome after axillary dissection in breast cancer: a prospective study, *Breast Cancer Res Treat*. 117 (2009) 625–630.
[3] M. Invernizzi, A. de Sire, L. Lippi, K. Venetis, E. Sajjadi, F. Gimigliano, A. Gennari, C. Criscitiello, C. Cisari, and N. Fusco, Impact of Rehabilitation on Breast Cancer Related Fatigue: A Pilot Study, *Front. Oncol*. 10 (2020).
[4] M. Mangone, A. Bernetti, F. Agostini, M. Paoloni, F.A. De Cicco, S.V. Capobianco, A.V. Bai, A. Bonifacino, V. Santilli, and T. Paolucci, Changes in Spine Alignment and Postural Balance After Breast Cancer Surgery: A Rehabilitative Point of View, *BioResearch Open Access*. 8 (2019) 121–128.
[5] A.C. Alarcón-Aldana, M. Callejas-Cuervo, and A.P.L. Bo, Upper Limb Physical Rehabilitation Using Serious Videogames and Motion Capture Systems: A Systematic Review, *Sensors*. 20 (2020) 5989.
[6] Microsoft, Azure Kinect DK, https://azure.microsoft.com/en-us/products/kinect-dk/, last access: 31.01.2023
[7] M. Antico, N. Balletti, G. Laudato, A. Lazich, M. Notarantonio, R. Oliveto, S. Ricciardi, S. Scalabrino, and J. Simeone, Postural control assessment via Microsoft Azure Kinect DK: An evaluation study, *Computer Methods and Programs in Biomedicine*. 209 (2021) 106324.
[8] N. Duarte, O. Postolache, and J. Scharcanski, KSGphysio - Kinect serious game for physiotherapy, 2014 *International Conference and Exposition on Electrical and Power Engineering (EPE)*. (2014).
[9] N. Belotti, S. Bonfanti, A. Locatelli, L. Rota, A. Ghidotti, and A. Vitali, A Tele-Rehabilitation Platform for Shoulder Motor Function Recovery Using Serious Games and an Azure Kinect Device, *Studies in Health Technology and Informatics*. (2022).
[10] A.L. Lee, R.S. Goldstein, M. Rhim, C. Chan, D. Brooks, and K. Zabjek, Reliability and validity of non-radiological measures of thoracic kyphosis in chronic obstructive pulmonary disease, *International Journal of Therapy and Rehabilitation*. 25 (2018) 648–654.
[11] T.K. Koo, and M.Y. Li, A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research, *Journal of chiropractic medicine*. 15 (2), 155–163.
[12] T.J. Carroll, R.D. Herbert, J. Munn, M. Lee, and S.C. Gandevia, Contralateral effects of unilateral strength training: evidence and possible mechanisms, *Journal of Applied Physiology*. 101 (2006) 1514–1522.
[13] F. Zhang, and A. Knoll, Systematic Error Modeling and Bias Estimation, *Sensors*. 16 (2016) 729.
[14] U. Özsoy, Y. Yıldırım, S. Karaşin, R. Şekerci, and L.B. Süzen, Reliability and agreement of Azure Kinect and Kinect v2 depth sensors in the shoulder joint range of motion estimation, *Journal of Shoulder and Elbow Surgery*. 31 (2022) 2049–2056.
[15] S. Jo, S. Song, J. Kim, and C. Song, Agreement between Azure Kinect and Marker-Based Motion Analysis during Functional Movements: A Feasibility Study, *Sensors*. 22 (2022) 9819.