A On-site Monitoring Device of Work-related Musculoskeletal Disorder Risk Based on 3D-Camera

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Abstract : A 3D camera-based on-site work-related musculoskeletal disorder risk assessment(WMDs) tool has been developed. The device consists of Kinect a 3D camera manufactured by Microsoft, a servo-motor, and a mobile robot. To complement inherent narrow field of view(FOV) of Kinect, Kinect is rotated according to PID servo-control algorithm by a servo-motor attached underneath, to track movement of a subject, producing skeleton-based motion data. With servo-control, full 360 degrees tracking of a test subject is possible by single Kinect. It was found from experimental tests that the proposed device can be successfully employed for on-site WMDs risk assessing tool.

Key Words : work-related musculoskeletal disorder, 3D camera, Kinect, tilt angle, risk assessment

1. Introduction

Work-related musculoskeletal disorders(WMDs) is one of the major work-related diseases and the economic burden of WMDs in Korea is steadily increasing\(^1\). An effective WMDs prevention may be achieved by evaluating risk factors on-site and informing the workers and employers of risk. Based on the degree of accuracy and precision, the WMDs risk assessment methods can be categorized into 1) observational methods and 2) direct-measurement methods\(^3\). The observational method is primarily based on direct observation of a worker during the course of work. It is easy to use, applicable to wide range of work environment but lacks in accuracy and bandwidth\(^3\). The direct measurement method uses postural data from the sensors attached to a worker. It is accurate, though intrusive and cost-intensive. A 3D camera-based observational method has become an emerging observational method due to the advent of low cost(under $200), accurate 3D cameras such as Microsoft Kinect, Intel RealSense, and ASUS Xtion.

The 3D camera is a depth sensor comprised of an infra-red laser transmitter and an infrared camera. A speckled pattern is projected onto the object in the sensor’s field of view. Measuring deformation in the reference speckle plane allows for creating a 3 dimensional map of the object. The 3D camera provides the skeleton-based position of the body joint from the 3D map by applying a randomized decision forecast algorithm\(^4\). Previous studies found that the skeleton-based motion data is useful for postural assessment\(^5\) and the 3D camera-based approach can be reliably used for motion capture and ergonomic assessment in work-environment setting with accuracy comparable to a commercially-available motion capture devices such as Qualysis Motion Capture Systems(Qualysis AB, Sweden).

A major drawback of the 3D camera-based ergonomic

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controller servo motor to enhance FOV, by which the 3D camera is rotated horizontally in a way that ensures the subject is on the centre of the FOV, allowing for the full coverage of the subject’s movement with single Kinect. In addition, Kinect is placed on a mobile platform for convenient deployment at the workplaces and tracking workers (Fig. 2). We chose Microsoft Kinect as a 3D camera for motion capture because of its long range of motion and the number of trackable joints offered.

2. Methods

2.1 Posture estimation using Kinect

Kinect, a 3D depth sensor provides the skeleton-based motion data of human within its FOV that consist of the positions of a set of joints, 25 to be exact for the most recent Kinect (Kinect sensor for windows v2) as shown in Fig. 3. Six people can simultaneously be tracked. The coordinate system for the skeleton data is a full 3D system with values in meters. Fig. 4 shows a series of skeleton-based motion data generated by Kinect for arm-raised-side postures.

The practical range of motion of Kinect is 1.0 ~ 4.0 meters and FOVs are 70 degrees in horizontal direction.
and 43 degrees in vertical direction. The Kinect can also be switched to Near Mode which provides a range of 0.5 to 2.0 meters for which a full skeleton might be partially unavailable but it is a good distance for acquiring seated postures. Because Kinect uses infrared (IR) for measuring depth, it cannot be used under direct sunlight.

2.2 Estimation of tilt angle of body segment

Given the position of the joint, the body segment vector may be defined along the line connecting the neighboring joint position vectors as in Eq. (1)

\[ \mathbf{S}_v = \mathbf{J}_{i+1} - \mathbf{J}_i = S_i i + S_j j + S_k k \]  

Eq. (1)

where \( \mathbf{S}_v \) is the segment position vector, \( \mathbf{J}_{i+1} \) and \( \mathbf{J}_i \) are neighboring joints position vectors, \( i, j, k \) are unit vectors along mutually orthogonal x, y, and z axes.

The tilt angle of a body segment can be easily found by calculating directional cosine of the body segment position vector as in Eqs. (2)–(4) (see Fig. 5 for definitions of the tilt angles).

\[ \theta_x = \cos^{-1} \left( \frac{S_x}{|\mathbf{S}_v|} \right) \]  

Eq. (2)

\[ \theta_y = \cos^{-1} \left( \frac{S_y}{|\mathbf{S}_v|} \right) \]  

Eq. (3)

\[ \theta_z = \cos^{-1} \left( \frac{S_z}{|\mathbf{S}_v|} \right) \]  

Eq. (4)

2.3 Expansion of field of view (FOV)

A single Kinect is not capable of covering a whole working area. To extend FOV of the Kinect, a servo motor may be attached to the bottom of Kinect and it is controlled as illustrated in Fig. 6 with a proportional and integral (PI) control algorithm known for its ease of use and robustness.

The center position (x, y, and z position) of a subject is tracked using the Kinect and a servo motor rotates it such...
3. Experimental Results

3.1 Verification of the tilt angles

To verify the tilt angle equations (Eqs. (2)–(4)), an experiment of lifting arm was performed with the Kinect acquiring the joint position; a subject was instructed to lift arms parallel to the ground from a relaxed standing posture (Fig. 8(a)) and lower arms to the starting posture (Fig. 8(b)). The procedures was repeated four times.

Based on the joint positions obtained from Kinect, the tilt angles of the upper arm was estimated using the tilt angle equations. The y-tilt angle ($\theta_y$) progressively increases to 90 degrees and decreases to 0 degree as the arm is lifted and lowered as shown in Fig. 9. A quadruple trial of lifting-lowering arm experiment show a pattern in the tilt angle measurement consistent with the motion of the arm. The x-tilt angle ($\theta_x$) also varied in a similar variation pattern with a maximum x-tilt angle of 80 degrees (Fig. 9). In contrast, the z-tilt angle ($\theta_z$) varied within 10 degrees bound as shown in Fig. 11, because the arm primarily moves on the frontal plane. Given neighbouring joint positions, the tilt angle of a body segment can be easily calculated by using Eqs. (2)–(4).
3.2 Servo control of Kinect to expand FOV

To demonstrate enhancement of the FOV with a servo-motor-controlled Kinect, the subject was instructed to walk at a walking speed of 4 km/hr along the circumference of a circle (radius = 1.5 m) with Kinect at the center as illustrated in Fig. 12. The servo-motor rotates Kinect to place the subject within the horizontal FOV of Kinect which is 70 degrees. At a distance of 1.5 meters from Kinect, the horizontal viewing distance spans from -1.05 to +1.05 meters.

The shoulder-center positions of the subject tracing the circumference of a circle are shown in Fig. 13. The horizontal positions are varied from -0.45 to 0.2 meters and the vertical positions are from 1.4 to 1.6 meters. Servo controlled Kinect allows for tracking the subject omni-directionally.
Fig. 15. Motor angle and horizontal position of shoulder centre vs. time.

Fig. 14 shows the distance of the subject from Kinect along with the servo-motor rotation angle in the polar coordinate. The measured distance traces a circular path with a radius of 1.5 meters. Without servo control the Kinect ceased to track a subject as the angle grows beyond Kinect FOV which is ±35 degrees. Also it can be found from Fig. 15 that the motor angle increases to counter the position change of the subject, placing the subject inside the horizontal FOV of Kinect.

4. Discussion

Skeleton-based motion data from the 3D camera can gauge worker’s exposure to risky working postures likely to result in WMDs by using the well-established posture analysis methods such as OWAS\(^7\), RULA\(^8\), and REBA\(^9\). Advantage of 3D camera for motion analysis has long been known to researchers that makes 3D camera-based motion approach to be a viable alternative to existing WMDs risk analysis methods. The cost of the device, however, prohibited an active use of the 3D camera for motion-capture-based WMDs research. Only for limited medical applications were they selectively used. These days, with information-communication technology (ICT) rapidly progressing, price of 3D camera exponentially drops and a 3D camera made by Intel(RealSense 3D camera, USA) is available under $100. A 3D camera and a notebook computer are only major hardwares required for WMDs-related research. Multiple 3D cameras can be dispatched at disperse locations in workplaces, monitoring worker’s activities including working postures, speed, and duration. With internet-connectivity, the collected data can be stored at the cloud server for real-time monitoring and future analysis.

Adding a servo-control to the 3D camera clearly dealt with FOV issues but still, there exists a occluding problem that part of body is obscured by its torso when the worker does not face the 3D camera. This self-blocking more or less degrades overall accuracy. Theoretical inference algorithm for finding an occluded joint position is available based on known joint position. Also, automated recording of worker’s movement during the course of work and statistical post-processing can decrease contribution of one measurement error to overall measurement accuracy. With aid of inference and statistical analysis it is expected to mitigate adverse effect of self-blocking.

5. Conclusions

With PI servo-control, inherently narrow FOV of 3D cameras such as Kinect and RealSense have been expanded to 360 degrees, allowing single 3D camera to be used as an on-site WMDs risk monitoring device. The servo-controlled 3D camera tracks a test subject omni-directionally, producing skeleton-based motion data from which the tilt angle of a body segment is analytically calculated. The process involves first identifying a position vector connecting neighbouring joints and then calculating the direction cosine of the position vector. Given the tilt angle, a variety of WMDs assessing methods can be systematically applied to estimate WMDs risks to which a worker is exposed.

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References

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