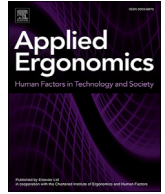




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Visualizing stressful aspects of repetitive motion tasks and opportunities for ergonomic improvements using computer vision

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ABSTRACT

Patterns of physical stress exposure are often difficult to measure, and the metrics of variation and techniques for identifying them is underdeveloped in the practice of occupational ergonomics. Computer vision has previously been used for evaluating repetitive motion tasks for hand activity level (HAL) utilizing conventional 2D videos. The approach was made practical by relaxing the need for high precision, and by adopting a semi-automatic approach for measuring spatiotemporal characteristics of the repetitive task. In this paper, a new method for visualizing task factors, using this computer vision approach, is demonstrated. After videos are made, the analyst selects a region of interest on the hand to track and the hand location and its associated kinematics are measured for every frame. The visualization method spatially deconstructs and displays the frequency, speed and duty cycle components of tasks that are part of the threshold limit value for hand activity for the purpose of identifying patterns of exposure associated with the specific job factors, as well as for suggesting task improvements. The localized variables are plotted as a heat map superimposed over the video, and displayed in the context of the task being performed. Based on the intensity of the specific variables used to calculate HAL, we can determine which task factors most contribute to HAL, and readily identify those work elements in the task that contribute more to increased risk for an injury. Work simulations and actual industrial examples are described. This method should help practitioners more readily measure and interpret temporal exposure patterns and identify potential task improvements.

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1. Introduction

Occupational ergonomics job analysis for hand-intensive repetitive manual tasks is rooted in the industrial and systems engineering approach, derived from traditional work measurement and time and motion study involving the systematic breakdown of tasks into their constituent elements (Armstrong et al., 1986; Dempsey and Mathiassen, 2006). This approach is central for work designers and engineers because it inherently relates specific aspects of the job to the risk factors of physical stress exposure for controlling their undesirable effects, including onset of fatigue or an injury. A limitation of this approach is that it is often subjective and time intensive for the analyst.

The development of quantitative upper extremity job assessment instruments and tools for evaluating physical stress exposure

and associated risk, however, often trades quantification of risk for the ability to directly identify specific job elements that contribute to the risk of injury, thus making it difficult for designers and engineers to identify the most hazardous job attributes and opportunities to apply interventions for reducing or eliminating the risk. Such instruments include the American Conference of Governmental Industrial Hygienists (ACGIH[®] Worldwide, 2001) Threshold Limit Value[®] (TLV[®]) for Hand Activity Level (HAL), and the Strain Index (Moore and Garg, 1995), to name a few. Parameters involved in such instruments typically include evaluation of frequencies, duty cycles and speed of movements.

Conventional job analysis involves either observations or sometimes measurements using instruments attached to a worker's hands or arms. Observational exposure assessment is convenient, but is considered subjective, inaccurate, unreliable (Brodie and Wells, 1997), and subject to considerable intra- and inter-observer variability (Bao et al., 2009). Furthermore, observational methods are not well-suited for evaluating temporal exposure patterns such as duration and frequency (Wells et al., 2007),

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especially for long-term viewing or for quantifying risk factor interactions, relying on tedious frame-by-frame video data extraction.

Kazmierczak et al. (2006) studied the agreement between observers analyzing assembly work patterns from video and found that although there was good overall agreement on the proportion and duration of activities, observers disagreed substantially on the results for a particular video recording. Disagreement between two observers on the time history of activity categories showed notable differences. Instruments offer more accuracy and precision, but are often cost prohibitive, unsuitable for the workplace environment, invasive and interfere with operations, difficult to interpret and require technical expertise, and are impractical for routine applications by occupational health and safety professionals in industry who have limited time and resources at their disposal (David, 2005).

Video has become an indispensable tool in ergonomics practice. The advent of video technology has greatly facilitated this approach and has allowed engineers, and often the workers themselves, an opportunity to observe and review the tasks in slow motion or one frame at a time in order to identify the hazards and opportunities for ergonomics improvements. A survey of Certified Professional Ergonomists conducted by Dempsey et al. (2005) reported that not only was a video camera the most used basic tool (96.1%), it was rated “very useful” by most (68%) of the participants, only second to a tape measure.

Computer vision has impacted a diverse field of applications, ranging from industrial robotics, intelligent and autonomous vehicles, security surveillance, manufacturing inspection, and human-computer interaction. Furthermore, digital imaging technologies are advancing ever smaller in size, finer in granularity, and faster in processing, while becoming less expensive and thus more accessible to businesses, organizations, and individuals in devices such as smart phones and tablets. New computer vision methods are now being researched and developed for occupational ergonomics applications. It is anticipated that these new tools will profoundly impact the future of occupational ergonomics and provide a variety of new instruments and techniques for design, analysis and evaluation in the practice of ergonomics.

Our laboratory at the University of Wisconsin-Madison is using computer vision for evaluating repetitive motion tasks for hand activity level (Chen et al., 2013), time and motion, duty cycle and maximum acceptable exertions (Akkas et al., 2016), and skill acquisition (Glarner et al., 2014; Azari et al., 2016), utilizing conventional 2D videos. The approach we developed is made practical by relaxing the need for high precision, and by adopting a semi-automatic approach whereby the analysts interactively selects a region of interest such as a hand or arm to track relative to a stationary region, rather than imposing an a priori model of the tracked activity (Chen et al., 2014). Consequently, the analysis complexity is greatly reduced and more tolerable of the numerous variations encountered in field video recordings of occupational tasks.

In this paper, a new method for visualizing task factors comprising HAL using computer vision is demonstrated. This method displays the spatiotemporal characteristics of task factors for the purpose of identifying patterns of exposure as well as suggesting task improvements. The technical principles for capturing video and deconstructing and displaying the frequency, speed and duty cycle components of tasks that are part of the TLV for hand activity from the tracked hand kinematics are first described. Then visualization techniques used to create displays for the ergonomics analyst to identify patterns of exposure associated with the specific job factors are described. Finally examples are provided using work simulations and actual workplace applications.

2. Methods and results

2.1. Nomenclature and video coordinate system

The method utilizes conventional video of a worker performing a repetitive task. Video segments are selected that contain a clear view of the hands throughout the task, made from a viewpoint aligned with the plane of motion, and contain stable camera movement. A cross-correlation template matching algorithm is used to track the worker's hand while performing a repetitive task. A region of interest (ROI) centering on the hand is indicated by the analyst to initialize the marker-less video tracking algorithm, which is fully described in Chen et al. (2014). The ROI location is tracked for each video frame using the algorithm. The result is a time series of points tracking the motions of the hand across the video clip.

The coordinate system used in this paper is shown in Fig. 1. For each video frame i of the N frames in a video segment, the algorithm calculates the horizontal location (x_i) and vertical location (y_i) of the center of the ROI within the video frame in pixels, and calculates speed for each frame.

The ROI speed was calculated using the equation:

$$S_i = \frac{r}{2} * \sqrt{(x_{i+1} - x_{i-1})^2 + (y_{i+1} - y_{i-1})^2} \frac{\text{pixels}}{\text{second}}; 2 \leq i \leq N - 1,$$

where r is the video frame rate (typically 30 frames per second), and N/r is the period (seconds) of a video frame. Associated with each (x_i, y_i) is a label of exertion $e_i \in \{0, 1\}$, $e_i = 1$ indicating if the hand location at the i th frame is part of an exertion, and $= 0$ otherwise. This label was obtained manually using MVTA software (Yen and Radwin, 1995) for the purposes of this analysis. The sequence $\{e_i; 1 \leq i \leq N\}$ consists multiple cycles of consecutive 1's followed by consecutive 0's, representing the when exertions are made by the worker during the task. The total number of exertions during the entire video clip is denoted by M . Ideally, with periodic hand movements, the duration of every cycle should be identical. In practice, however, some variations will occur. Since in one frame the hand movement can only belong to one cycle, the length of the cycle (in units of number of frames) that frame i is in is denoted as T_i . This is also manually labeled in the MVTA software for the current study.

Since speed was measured using the tracking algorithm in pixels per second, it had to be calibrated against physical dimensions. An object of known dimensions was chosen in the video, and the length was measured using the MVTA software. The data was calibrated based on the dimension of an object in the video in relation to its known dimension. When a reference object was not available, the hand breadth was measured in pixels and average hand breadth (9.04 mm for males and 7.04 mm for females) from the 1988 US Army Anthropometry Survey (Greiner, 1991) was used to convert from pixels to millimeters.

2.2. Video parameters

Using the x, y location and hand kinematics obtained from the video tracking algorithm, we can calculate global statistics for the entire video clip, be defined as follows:

Average exertion frequency (F) is:

$$F = \frac{\text{total number of exertion cycles}}{\text{total duration of video clip}} = \frac{M}{(N/r)} = \frac{M \cdot r}{N} \frac{\text{cycles}}{\text{second}}$$

Duty Cycle (D) is:

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