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A summative scoring system for evaluation of human kinematic performance

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ABSTRACT

Evaluation of human kinematic performance is essential in rehabilitation and skill assessment. These services are in high demand where the improvements made due to exercises need to be regularly assessed. In some relevant industries there is a need to evaluate their employee capabilities quantitatively for accident compensation and insurance purposes. In particular, these assessments are preferred to be based on more quantifiable measures in a standardized form ensuring accuracy, reliability, ease of use and anywhere anytime information to the clinician. Therefore, it is necessary to have an efficient mechanism for evaluation and assessment of human kinematic movements as the current motion matching and recognition algorithms fall short due to characteristically strict specifications required in numerous health care applications. In this paper, we propose a summative approach using a double integral to define a *closeness* between two trajectories typically generated by human movement. This approach can be considered as a spatial scoring mechanism in the evaluation of human kinematic performance as well as in movement recognition applications. Several experiments based on computer simulations as well as real data were set up to examine the performance of the proposed approach as a scoring mechanism for the evaluation of human kinematic performances. The results demonstrated better characterization of the movement assessment and motion recognition ability, with a recognition rate of 86.19%, than the currently used methods such as Gaussian mixture models and pose normalization employed in motion recognition tasks. Finally, we use the scoring mechanism to analyze the proximity in human kinematic performance.

1. Introduction

Occupational health issues receive interests across a wide spectrum of industries [14]. A report in 2006 estimated that direct U.S. workers' compensation costs for disability related workplace injuries and illnesses were $48.6 billion [4]. Therefore, studying musculoskeletal disorders and analysing kinematic performances are in high demand to improve existing techniques. Analysing kinematic performance using non-contact forms of measurements has advanced significantly due to the development of advanced sensor technology. One of the first research work in this area was Coley's study [5] where the outcome evaluation in post shoulder surgery rehabilitation was validated using 3D kinematic sensors employing traditional questionnaire based scoring mechanisms, i.e. Disabilities of the Arm, Shoulder score (DASH) [9], Simple Shoulder Test score [11]. In more recent work, Zariffa [25] and Liu [13] investigated the assessment of functional properties after spinal cord injury. Liu presented a novel myoelectric pattern recognition based approach for hand function restoration after incomplete cervical spinal cord injuries [13].

Electronic systems to support kinematic measurement for clinical use in the rehabilitation space were considered in recent years [5,15,16,20]. These systems, which are cheaper, portable and easy to use, are expected to assist therapists and health care professionals to provide services with improved quality of care. A significant advantage of these systems is their ease of use as a home-based application, potentially reducing the frequency of patients' travelling to the hospital. Indeed this will provide more up-to-date information of the functional capabilities and their improvement to the relevant therapist or the appropriate health care provider to a preferred regularity. This is likely to result in an enormous impact

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on the recovery time, personnel cost saving and the much needed cost saving for the health care sector without risking the quality of care as it provides regular information that has simply not been available before.

Evaluation of kinematic performance in Coley's study is simple and straight forward [5]. However, analysis based only on angular velocity and spatial accelerations does not take full advantage of all the information extracted from 3D kinematic sensors. Motion analysis has long been studied in many fields, and is not limited to the medical area by any means. Hardware developments such as the wearable system Fitzgerald introduced [7] combined virtual reality to capture motion effects to facilitate biofeedback. Using a combination of a laser tracker and a magnetic tracker, Zetu optimised the physical routines of process workers in a manufacturing environment in order to improve the production efficiency [26]. Humm investigated bio-mechanical patterns of ballet dancers [8]. A Vicon© system (Vicon Motion Systems Ltd) and an electromyograph was used to record and understand typical movement trajectories in ballet dancing to reduce injuries. In sport motion analysis, Wang developed a novel algorithm to match the expert's 3D reference motion with a performer's 2D input video [23]. Despite lacking 3D information of the performer, this algorithm was capable of computing 3D posture errors that reflect the performer's actual motion errors. The recovery after shoulder surgery was studied and evaluated using 3D kinematic sensors by Coley [5]. Ni used fuzzified neural networks to perform human activity monitoring which included walking, running, sitting, lying and standing [18]. In more recent studies, Li introduced a two synthetic component encoding model for human action based on trajectory tracking [12]. Banos presented a study to characterise the windowing procedures and looked at the impact of the window size in 33 fitness activities [1]. The activities varied from movement such as lateral elevation of arm and knee bending to complex actions such as cycling and waist rotation. Barthelemy proposed a linguistic type approach for decomposition of motion into atomic components for 3D trajectories [2].

The main idea in trajectory-based object motion analysis is the comparison between a new input trajectory with pre-determined motion trajectories in a database (motion matching). The first generation of matching algorithms used a simple point to point distance measure between two trajectories. Motion matching for the purpose of motion recognition using a point to point distance measure soon encountered limitations as data from similar movements tend to appear differently due of various factors such as scale, rotation, sampling rate and unequal sampling causing point to point distance measures ineffective. Needham improved this technique by calculating the area between these trajectories [17]. However, this technique only worked in 2D. To overcome this problem, a new generation of matching algorithms appeared. Local features of trajectories called signatures were defined for motion recognition [6,24]. This signature performs better due to its flexibility than other shape descriptors such as B-spline, NURBS, wavelet transformation and Fourier descriptor. Trajectories represented by the signature and the descriptors are invariant to spatial transformation. However, these algorithms which perform well in motion recognition tasks, are not suitable as scoring mechanisms in kinematic performance assessment systems due to the scale differences and incorrect or undesirable motion. Using the point to point distance measure as a trajectory matching technique is deemed ineffective [21] particularly if the data has been captured with different sampling rates which is generally the case in most practical situations. In this paper, these challenges are addressed where appropriate technique to evaluate the human kinematic performance more effectively was introduced using a better scoring mechanism.

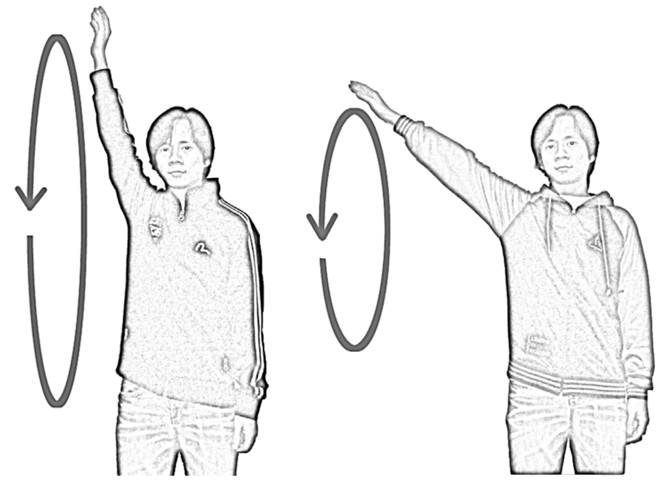

Fig. 1. Illustrating the need for scale sensitivity. The arm angle of reference motion in the left is 80°. The arm angle of the practice motion in the right is 45°. Both motions are circular motions with different radius.

2. Material and methods

2.1. Spatial score

A scoring system is an essential component in kinematic performance assessment and it can contribute significantly to the overall assessment process potentially impacting therapeutic decisions. These enable the evaluation of the exercise movements performed by a patient with respect to the prescribed reference motions prepared by a therapist or a health care professional. Scoring mechanisms should essentially provide a measure of the *proximity* of a patient motion to the reference motion. Also a good scoring mechanism should satisfy the following conditions: invariant to velocity and sampling rate, sensitive to scale changes and dissimilarity. Therapists, health professionals and patients cannot be expected to perform movements with consistent velocity patterns; insensitive to velocity fluctuations. Therefore, the scoring mechanisms need to consistently yield the same scores for motions having the same path but different velocities and/or measured at different sampling rates. Naturally, the scoring mechanism shares a common characteristic with other trajectory recognition algorithms where a lower score for dissimilar motions and higher score for similar motions. However, it is not practical to use trajectory recognition algorithms for scoring system to evaluate the kinematic performance as scoring mechanisms need to be sensitive to the scale differences. Referring to the example depicted in Fig. 1, the reference motion and the practice motion are circular motions with different size due to different arm orientations. The hand angle in the reference motion and the practice motion is about 80° and 45° respectively. In this scenario, most of the trajectory recognition give a perfect score or recognised as an identical motion. However, this does not reflect the mechanism in the scoring system used to evaluate human kinetic performance where a lower score should be given due to the scale difference or in brief, for actions that are further apart. Note that in the scoring systems, skeleton height and bone length of therapist and patients are scaled to the same number, or in other words, they are normalised.

With these specific requirements, we propose a novel approach to serve as a scoring mechanism. Our approach uses a summative approach involving Euclidean distances to define a *scoring* mechanism for two 3D trajectories. The underlying characterisation is presented as follows.

Considers a directed curve ξ_1 with a length l_1. A point E with coordinate $(x_E, y_E, z_E)^T$ on ξ_1 is described as $E = \xi_1(u)$ with $0 \le u \le l_1$.