REDUCING SENSOR DENSITY REQUIREMENTS FOR KINEMATIC CONTROLLERS IN A FULL POSTURE YOGA GAMING APPLICATION

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Abstract:
Integration of whole body movements with virtual reality environments and computer games has many benefits for exercise training and rehabilitation. Such applications can serve as a virtual personal trainer for different exercise therapies. Current examples of this are based on provision of visual feedback to the user via a webcam yet these allow the player to deviate from the desired exercise sequence without direct warning or feedback. This can be solved by tracking body movements using orientation sensors. However, tracking and providing real time feedback for whole body movements for exercise therapies such as Yoga can prove very complex and require the use of a large number of sensors on body segments. In this paper we describe a methodological approach that can facilitate the development of a body movement driven Yoga exercise computer game that can discriminate player performance level with the use of minimum instrumentation.

Key Words: computer game, therapeutic exercise, kinematics, performance level, joint angular displacement, wearable feedback system, yoga, sensors, minimum instrumentation, 3D motion capture.

I. Background & Purpose

Therapies such as yoga have been shown to have many therapeutic benefits in rehabilitation including enhancing postural awareness and reducing chronic pain & stress. This paper reports on studies and analyses on movement based relaxation activities such as Yoga with the aim of determining biomechanical correlates of action fidelity that can be harnessed to automate some aspects of the instruction cycle in the form of a gaming system. This work feeds into a technical project discussed elsewhere, which is ‘The E-motion System’ (a movement-based biofeedback application), to develop a computer game in which the player’s performance is determined by their ability to master one of these physical arts and in doing so bring about a state of mental relaxation. A wireless, unobtrusive garment -based physiological and kinematic measurement system provides our primary method of communication with the game. This lightweight garment will ultimately monitor heart and breathing rate, muscle activity and alignment of body segments using embedded invented miniature sensors.

A typical scenario of the final game could be that the player wears the suit fitted with motion tracking sensors. On the screen will be an animation of a yoga expert guiding the player through the different yoga poses. This guidance will be given visually on the screen and also instructions will be given through audio. The player will then follow the instructions from the computer game to correctly perform the yoga poses. The sensors embedded in the suit worn by the player will continuously give feedback to the game as to the player’s position and where each part of the body is in real time. As the feedback is monitored from the sensors within the suit the game will know if for example the player’s knees are flexed in a particular yoga pose when they should be mid-range. Verbal instructions will then be given to the player to reduce the flexion of their knee. This artificial intelligence will characterise and monitor the player’s performance in the game and be able to give them a score. Also a players skill and level of performance will be remembered so that when the player goes back to play the game, the game will know how to instruct them further to perform the correct yoga pose so the game will act as a virtual trainer for yoga.

In the game, success is determined by the player reproducing the physical postures displayed by a animated model on the screen whilst still maintaining a relaxed and controlled breathing pattern. Feedback is provided by means of reproduction of the player’s body image on screen. Quality of movement and posture, and degree of mental relaxation will determine the player’s performance. This system could be used by patients suffering from many conditions including stress, anxiety disorder and chronic pain. The envisaged complete system could also eventually lead to the development of wearable feedback training systems for other exercise therapies such as core stability training.

Clearly one of the most significant challenges in such a project is the development of an expert system capable of rating and classifying user input with respect to varying levels of performance. In addition graded progression from novice to expert practitioner has to be incorporated for playability purposes. Later stages of the project will involve design of methods for processing of user input to affect changes in the game state of the virtual reality application to facilitate an effort free feedback process. The final part of this whole project will be the design of a suitable virtual reality game, e.g. ‘The E-motion System’, which would enhance and augment the experience of

Yoga or other therapies for a user through the facilitation of incremental improvement recognition and appropriate game progression strategies. The primary contribution of this paper however is the development of a knowledge base from which heuristics regarding biomechanical correlates of effective yogic positions can be ascertained for the purposes of game developments in this area. In particular we show how the required numbers of sensors for adequate assessment of Yoga postures for such a game can be significantly reduced through thorough biomechanical analysis.

The rest of the paper is composed as follows: Section II Method overview, Section III Methods, Section IV Results, Section V Conclusion, Section VI Discussion, Section VII References ending with Section VIII Author's Biography.

II Method Overview

A 6 camera 3D motion capture system was used to collect kinematic data from upper and lower extremity joint angular displacement (including extremity joints, trunk and head) during performance of the Sun Salutation yoga exercise sequence in 11 healthy adults, divided into expert (n=5) and novice (n=6) groups. Kinematic data relating to all joints were analysed and compared between expert and novice groups for each of the 8 separate poses included in the exercise sequence and the critical body joints were identified.

III. Methods

The CODA motion capture system (Charnwood Dynamics, UK) was used to track motion and movement of the joints. The CODA system contained three cameras mounted on a rigid frame. The kinematic data was recorded using the 2 sets of CODA cameras, 6 cameras in total, placed at a 30 degree angle to each other on the right side of the subject to give maximum detection of the markers from the right side of the body.

These cameras were the detectors and high-accuracy tracking sensors which were pre-calibrated for 3-D measurement. Two sets of these units were used to give an 'extra set of eyes' and maximum redundancy of viewpoint. The cameras at each end of the CODA system unit measured horizontal movement and the middle sensor measured vertical movement. This design allowed each CODA unit to be calibrated to give 3D coordinates. The cameras had flat windows instead of lenses which sensed the position of the small infrared Light Emitting Diode (L.E.D) markers. In this system the LED markers were placed on the subject at the joints of interest and their location in image frames tracked to yield a measure of the motion enacted with very high resolution. Through using the six cameras varying degrees of fidelity could be obtained. The LED markers were powered by small rechargeable battery packs called marker driver boxes. The LED markers were plugged into the battery packs and each marker driver box had a unique identity so the CODA system always knew which marker was which.

To record the kinematic data a protocol was first designed for the study. Approximately 40 pilot studies were conducted using CODA sensors and placing them at various points on the body to be able to measure joint kinematics. In total 16 markers and 8 driver boxes were used. Due to the number of markers and battery packs available it was then decided that only the right side of the subject's body would be analysed, thus giving kinematic data for the right side of the body only. This also meant that the markers had maximum visibility for the cameras which were positioned to the right hand side of the subject as shown in Figure 1.

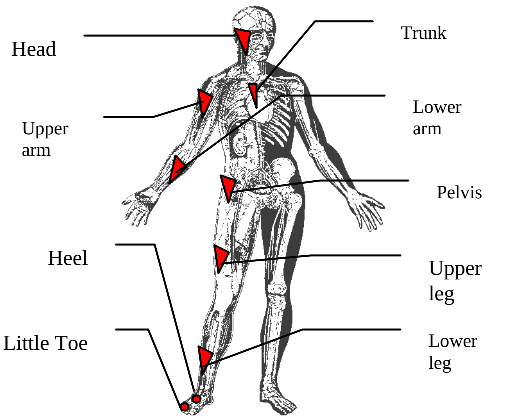


Figure 1: Placement of sensors

Each subject was required to complete the 12 set of yoga postures in the classical sun salutation sequence, which includes 8 different poses as shown in Figure 2.

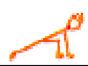
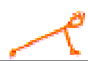
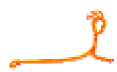
Pose Number in Sun Salutation Sequence	Name of Pose (Asana)	Picture Showing Pose
Pose 1	Mountain Pose Tadasana	
Pose 2	Hands Up Pose Urdhva Hastasana	
Pose 3	Head to knees Pose Uttanasana	
Pose 4	Lunge Pose Ashwa Sanchalanasana	
Pose 5:	Plank Pose Plank Asana	
Pose 6:	Four Limbed Staff Pose Chaturanga Dandasana	
Pose 7:	Upward Facing Dog Pose Urdhva Mukha Svanasana	
Pose 8:	Downward Facing Dog Pose Adho Mukha Svanasana	

Figure 2: The eight different poses in the Sun Salutation Sequence

The subjects were 11 healthy adults, divided into expert (n=5) and novice (n=6) groups. Each subject performed all the yoga poses in a slow controlled manner under the direction of the investigator, who was also a qualified yoga instructor.
The sequences were also recorded on video. The sequence was repeated and recorded 5 times for each subject and saved separately for each sequence. Each subject attended one testing session which lasted approximately one hour.

Kinematic data relating to all joints were analysed and compared between expert and novice groups for each of the 8 different poses included in the exercise sequence as shown in Figure 2. Both group's kinematic profiles were compared to identify the critical body joints that discriminated between groups..

The kinematic variables associated with the chosen yoga poses were quantified. This entailed carrying out a cross sectional study of yoga kinematic patterns in a motion analysis laboratory. Upper and lower extremity joint angular displacement including spinal alignment of markers were measured and recorded in both groups, expert and novice. This was carried out using a LED (Light Emitting Diodes) detection using a CODA motion capture system (Charndyn Electronics, UK). Averaged kinematic profiles were calculated and kinematic 'key points' were identified for each exercise and analysed.

The data was analysed for the full sun salutation sequence in CODA Motion's software programme for each subject and the three sequences with the greatest marker visibility were chosen for each subject out of the five sequences recorded. A different setup was created in CODA Motion's software for each subject's individual sequence with the necessary offsets, a total of 33 setups (3 sequences X 11 subjects in total). Graphs showing change in movement of individual markers were analysed so as to see when the subject was static i.e. in a particular pose. A stick figure diagram was also created in each setup for each subject so as to replay some of the movements of the subject. This stick figure diagram and the analysis of the graphs showing static marker movement together with video capture of the performed sun salutation sequence in CODA, enabled timelines to be created for each pose for each subject for each sequence so as to know when each pose was performed in the whole sequence. To enable the CODA software to give joint angular displacement for the elbow, knee, head, ankle, shoulder, trunk and hip, for each of the poses, vectors were input so as to create vector lines between the 4 markers in question so joint angles could be analysed. An example of a vector created for the knee joint is detailed below in Figure 3.

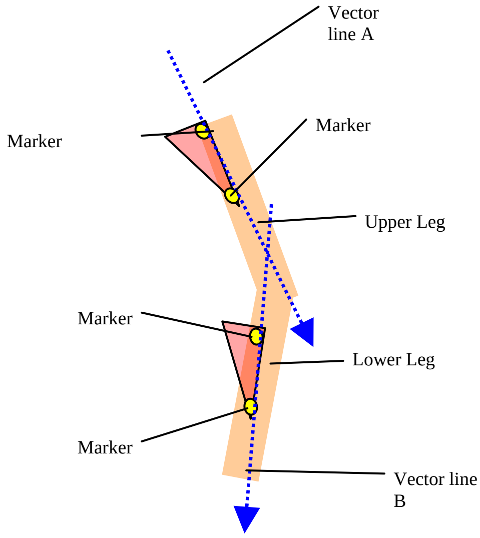


Figure 3: Vectors for knee joint

IV. Results

Joint angular displacements for the elbow, knee, head, ankle, shoulder, trunk and hip, for each of the poses were analysed. Our results indicated that knee joint angular displacement in the sagittal plane could be used to discriminate between groups in 6 out of the 8 key poses in the Sun Salutation. The graph below, Figure 4, shows the range for each group for the knee joint angular displacement for each of the eight poses in the sun salutation sequence. The dots on the end of each line are the range of standard deviation for each group, i.e. expert and novice. The green line is for the novice group and the blue line for the expert group.

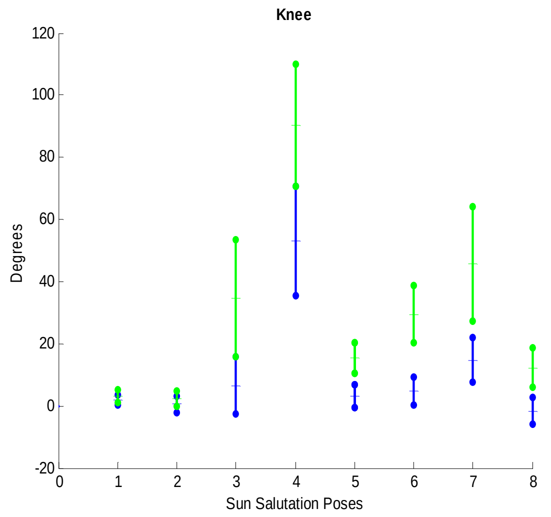


Figure 4: Graph showing joint angular displacement (degrees) for the Knee for each of the eight poses in the sun salutation sequence.

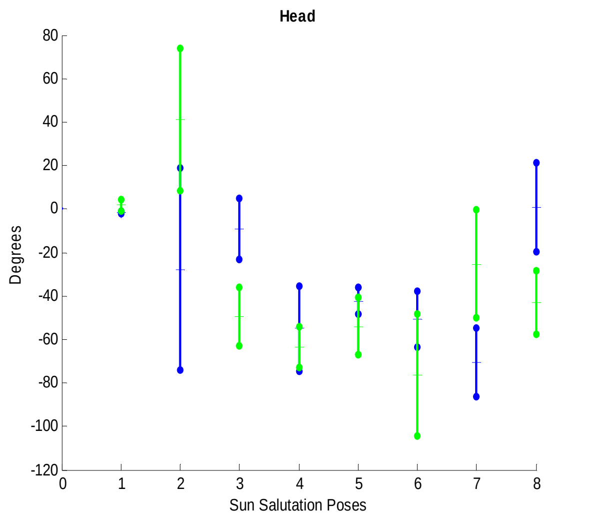


Figure 5: Graph showing joint angular displacement (degrees) for the Head for each of the eight poses in the sun salutation sequence.

Figure 4 shows that the joint angular displacement (in degrees) for the knee is different for the two groups. For each pose the knee can be measured with sensors and from this it can be easy to determine whether a person is a novice or an expert for 6 out of the 8 poses.
Whereas if the Elbow joint angular displacement is measured, as shown in Figure 6, it can be seen that you are not able to discriminate between both groups for any of the poses, as the novice group's range of standard deviation is greater than the experts and also overlaps the expert group range in most poses.

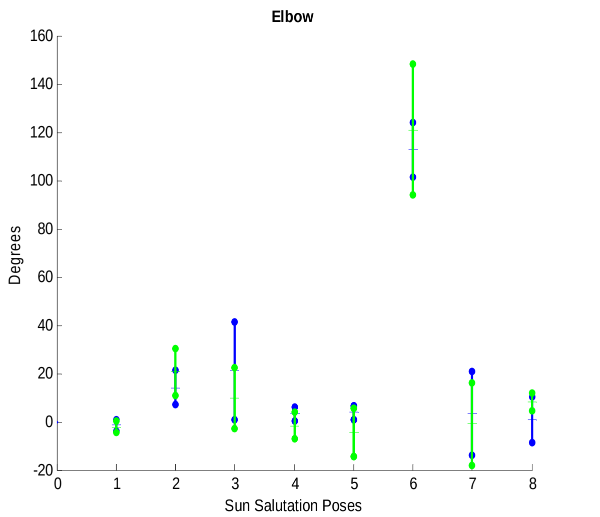


Figure 6: Graph showing joint angular displacement (degrees) for the Elbow for each of the eight poses in the sun salutation sequence.

From the graphs you can also see that the just from the head and knee sensor, Figures 4 &5, you can discriminate between the two different levels for 7 out of the 8 poses in the sun salutation exercise sequence. For the knee sensors, poses 1 and 2, both of which involve standing upright, indicate that both groups have similar knee joint angular displacement and therefore you can not discriminate between the groups. However, the graph showing the head movement indicates again that for 4 out of the 8 poses you can determine the performance level of the subject, and one of these poses is pose 2 which could not be distinguished by the knee sensor alone. The only pose left, out of the 8 poses, to discriminate performance when using the knee and head sensors is pose 1. However pose 1 in the sun salutation sequence is standing upright and is the pose where all the necessary offsets were input in CODA motion's software for each person. If it was absolutely required to distinguish between the groups for pose 1, the standing upright pose, a third set of sensors could be introduced which discriminates pose 1. The ankle joint angular displacement can therefore be added as this distinguishes pose 1 better, Figure 7, and then this gives you the performance level for all 8 poses separately.

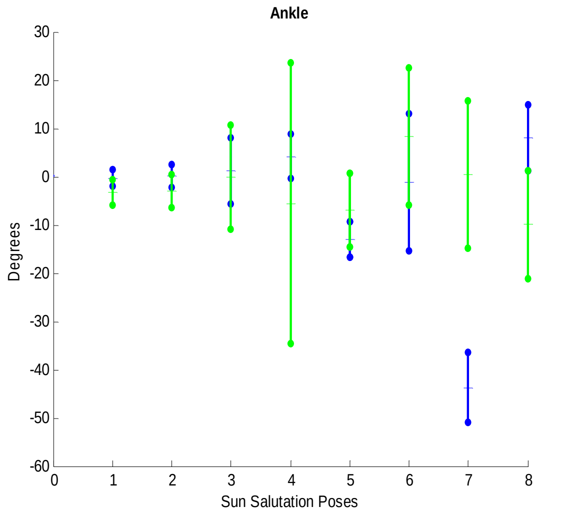


Figure 7: Graph showing joint angular displacement (degrees) for the Ankle for each of the eight poses in the sun salutation sequence.

V. Conclusion

These results suggest that a game based on the yoga sun salutation exercise sequence could be developed using a limited amount of sensors. For example one set of sensors, monitoring the knee joint position can discriminate between different levels of skill performance for 6 out of the 8 poses. When the knee sensor is combined with the head sensor it allows you to distinguish between the groups for all the poses apart from pose 1, which is standing upright pose. If it was required to discriminate performance levels for all 8 poses, including pose 1, then the ankle sensor could be introduced to the head and knee sensors. Therefore using three sets of sensors, monitoring knee, ankle & head joint position can be used to discriminate between different levels of skill performance rather than using 8 sets of sensors. Combining data from these three sensors with visual feedback from a webcam would afford a low cost method of providing a virtual personal trainer that can objectively measure performance. This methodological approach could be of value in development of games based on exercise sequences.

VI. Discussion

Analysis shows that from this method the knee, which showed significant differences for 6 out of the 8 poses, was the critical body joint that discriminated between groups and was therefore the most significant source of differences between the groups. The joint angular displacements for the other sensors showed that any significant difference in performance level could only be seen for a maximum of 4 out of 8 poses, which can be seen in the head sensor. The joint angular displacement for the elbow on the other hand, shown in Figure 6, doesn't show any significant differences for any of the poses and therefore is not a critical body joint for discriminating between levels.

So by using limited instrumentation, i.e. 3 sets of sensors on the head, knee and ankle, you are able to discriminate the different performance levels of the sun salutation sequence for all 8 poses and there is no need to use 8 or more sets of sensors which is very complex and requires the use of a large number of sensors on body segments, which also makes it difficult to perform the poses comfortably and correctly. The number of sensors can be further reduced if pose 1, standing upright is not included in the analysis and then only two sets of sensors are required for the head and knee to discriminate between performance level.

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VIII. Author Biography

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