Speckled Tango Dancers: Real-time Motion Capture of Two-Body Interactions using on-body Wireless Sensor Networks

D. K. Arvind
Research Consortium in Speckled Computing
School of Informatics, University of Edinburgh
Edinburgh EH16 5NT, Scotland, UK
e-mail: dka@inf.ed.ac.uk

Aris Valtazanos
Research Consortium in Speckled Computing
School of Informatics, University of Edinburgh
Edinburgh EH16 5NT, Scotland, UK
e-mail: A.Valtazanos@sms.ed.ac.uk

***Abstract*— This paper describes the application of a wireless network of on-body inertial sensors for the capture of 3-D motion of Tango dancers. Accomplished Tango dancers exhibit both individual flair and good co-ordination between partners. We have identified features which reflect the performance of both the individual (such as the angle of bend of the dancer's chest and synchronisation of the movements between the chest and the feet), and of the partnership (correlation of the dancers' chest movements). These features have been captured in the live data from on-body sensors and used to characterise the dancers' performance. The aim in the future is to design a dance tutoring tool which will analyse the sensor data and provide immediate feedback for improvement. The system can be extended to the analysis of other activities involving physical movement which have to be captured unobtrusively for real-time analysis and feedback.**

Keywords - body sensor networks; wireless sensor networks; wireless motion capture; tango dance

I. INTRODUCTION

A number of methods have been suggested for tracking the movement of dancers, who are either single subjects or part of an ensemble. The use of cameras is an obvious choice [1], although the vision analysis tools [2] are computationally expensive, and limited by problems due to lighting conditions and occlusion. In order to overcome these issues, fibre-optic, joint-bend sensors on the knees and elbows have been employed with varying degrees of success [3]. This solution is cumbersome due to the number of wires which are required to connect the sensors to the single radio worn as a back-pack [4]. A wireless solution [5] has been proposed in the form of 6-axis inertial measurement units, each comprising of a radio and three orthogonal gyroscopes and accelerometers, worn on the wrists and ankles of the dancer to capture local motion. The data from the sensors on an ensemble of dancers is collected via a high-speed RF network and the monitored activity is used to provide musical feedback. The aim was to identify different classes of activities, such as translational and rotational motion, and the use of the collective motion (such as three dancers raising and lowering their right hands in unison) as cues for musical events.

One of the outcomes of research in Speckled Computing [6] at the University of Edinburgh, has been the development of a compact, fully wireless, full-body 3-D motion capture system. Two novel contributions reported in this paper are: for the first time, Tango dancing has been analysed using on-body wireless sensor networks; and features which characterise individual dancers and their interactions have been identified for capture and subsequent analysis.

II. THE ORIENT MOTION CAPTURE SYSTEM

The Orient Motion Capture System [7] demonstrated for the first time, fully wireless, full-body, 3-D motion capture in real time using on-body network of fifteen custom-designed Orient inertial sensor devices (Figure 1). The system is free of infrastructure such as cameras [8][9], magnets, or audio receivers, and does not require special suits to be worn to contain the wires as in the cases of Xsens's Movens [10] and Animazoo's IGS-190 [11].

The compact Orient device measuring 36x28x11mm and weighing 23gms (including the custom-designed Perspex casing and Velcro straps) contains three 3-axes sensors: gyroscope, accelerometer and magnetometer and a temperature sensor. The nine sensors are sampled at up to 512 Hz, and a positional update rate of up to 64 Hz is achieved over the wireless network of 15 devices for full-body motion capture using a modest low-power 250 kbs radio. This is achieved thanks to an efficient local orientation estimation algorithm in the Orient device firmware which runs on a 16-bit dsPIC processor, and which reduces the communications data by 79% compared to existing methods [6]. Its onboard ADC is used to sample the inputs of the analog sensors: rate gyroscopes, magnetometers and accelerometers in each axis, plus temperature monitoring to allow compensation of the thermal response of the sensors. When multiple Orient devices are used together, their measurements are synchronised and their results transmitted across the radio channel in sequence, so that a complete frame's data can be

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assembled at the base-station (Figure 1, top-right) within milliseconds.

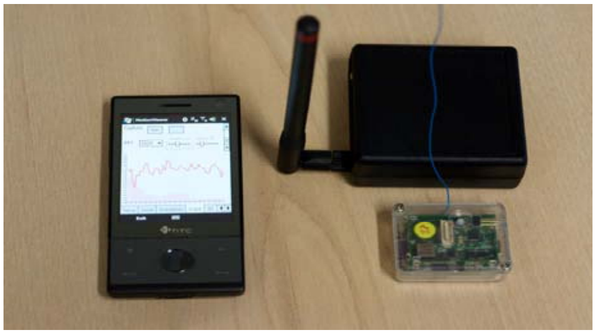


Figure 1: (Clockwise bottom-right) Orient-3 device, mobile phone, Orient base-station.

The base-station has USB, Bluetooth and WiFi interfaces which can bridge to a mobile phone (Figure 1, left) or PDA for viewing the visual representation of the results.

The Orient device captures full-body motion data at the maximum update rate of 64 Hz for around 150 minutes from a full battery charge. The 120mAh lithium polymer battery and charger are integrated into the device, with charging as simple as plugging in a lead, even when the device is held in a strap for use. The whole device can be placed into a low-power, sleep mode for weeks at a time, whilst being ready for use within a couple of seconds of being woken by a radio signal.

A simple calibration process requires the performer to hold briefly, just for a few seconds, a pre-determined stance which enables the alignments between the Orient devices and the performer's body segments to be automatically accounted for.

The MotionViewer software provides an interface (Figure 4) for interaction with a network of Orient devices. The software comprises of five main subsystems: Device Interface, Forward-kinematic rigid-body model, Project Management, Real-time visualisation, and a Plugin API (see Section 3).

The Device Interface is used to configure individual Orient-3 devices and set up a network to perform motion capture. The base-station with its USB, Bluetooth and WiFi interfaces acts as a bridge between the Orient devices and the host which could be a PC, PDA or a mobile phone. The interface is designed to be usable as a library for stand-alone applications, in addition to its use in MotionViewer.

The Rigid-body Model provides the translation from the orientation data gathered by the network of Orient devices to a real-time 3D model of the dancers. The model consists of a number of joints connected by rigid rods to form a simplistic model of the dancer's skeleton (Figure 4). The proportion of the sizes of the rods in the model should correspond to the relative sizes of the limbs of the performer. Rotation data from each Orient device is mapped uniquely to a rod (Figure 6), and after each frame of data the full state of the model is updated using a forward-kinematic method.

III. The Physical Model

The Argentinian Tango can best be described as a dialogue of improvised body movements between partners dancing at close quarters. The dancers face each other, staying as vertical as possible, with the shoulders and hips moving in parallel without any leaning or hanging. The leader (usually the male) leads from the waist downwards, with the legs and feet moving in precise co-ordination, meeting and following each other in a variety of ways. The follower (usually the female) moves independently without being propelled by the leader, while maintaining close connection effortlessly. The dancers feel the partner's transfer of weight and follow it while intending a pause for as long as possible within every step with both feet on the floor even as the weight is entirely on one foot, and as the body moves with the partner. The Orient inertial wireless sensor network has been used for real-time motion capture in applications including sports [12], sonification of gestures [13], and improvisational dance performances [14]. In all these examples, the motion capture and analysis was concerned with a single individual. The introduction of a second body poses new issues which are addressed in this paper. In particular, the posture of each body alone is insufficient to understand the physical interactions between the dancers which is central in the Tango. A significant part of the analysis is the correlation of the motion of the partners, such as the angles between their chests which should ideally be parallel.

A. *Identificaiton of features of interest in Tango*

The Tango is interesting because it provides scope for both individual flair and good co-ordination. The following four features capture this tension between the individual and the couple.

Individual features:

- The extent of bending of the chest
- Synchronisation between the movement of the chest and the foot

Collaborative features:

- Difference in the angle between the two chests over time
- Correlation of chest movements over time

The position of the chest and its motion are important features of an accomplished Tango dancer, and the following sections provide an explanation of how this is central to the measurements and analyses.

B. Measurement of the chest-bend

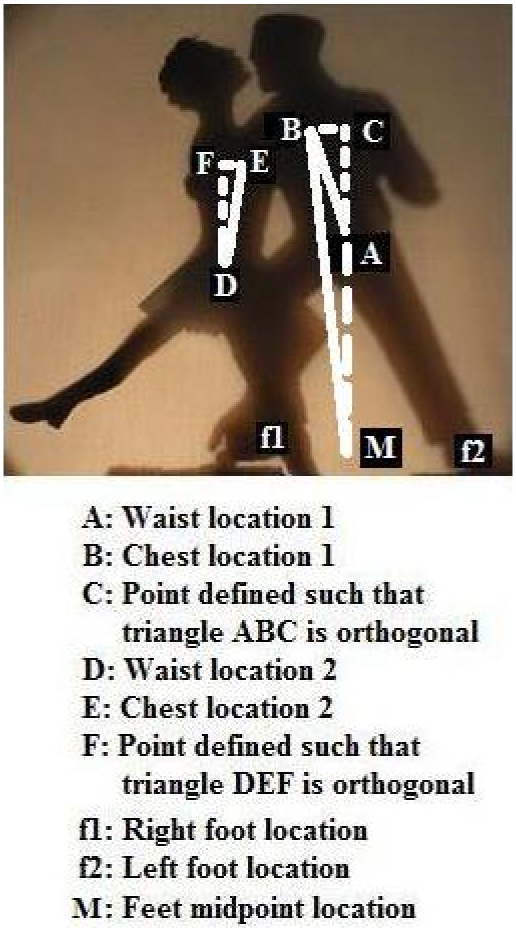


Figure 2: Physical model of the dancers

Figure 2 shows the relative positions of the waist (point A) and the chest (point B) which are used to calculate the bend in the chest. A new point C is defined such that the triangle ABC is orthogonal, with angle ACB being the right angle. The *angle of the chest-bend, θ,* is defined as:

$$\hat{\theta} = B\hat{A}C = \arctan\left(\frac{BC}{AC}\right)$$

A slight bend in the chest of a dancer is considered to be good style in Tango dancing. Conversely, a larger angle or a zero angle would be viewed as poor execution of the dance. The optimal chest-bend angle, *o,* was defined to be at 10 degrees, and the difference, δ, of an input angle, ι, from this value was the evaluation metric for this feature:

$$\delta_{CB} = \iota_{cb} - o_{cb}$$

A dancer should minimise this value, which should tend towards zero for satisfying this feature.

C. Synchronisation between the chest and feet movement

The first set of calculations required to evaluate this feature is similar to the one discussed in Section 2.2. The main difference is that point M is defined to be the *midpoint* of the positions of the two feet, *f1* and *f2*:

$$M_{(x,y,z)} = \frac{f1_{(x,y,z)} + f2_{(x,y,z)}}{2}$$

The angle θ is once again calculated to determine how the motion of the chest relates to the motion of the feet:

$$\hat{\theta} = B\hat{M}C = \arctan\left(\frac{BC}{CM}\right)$$

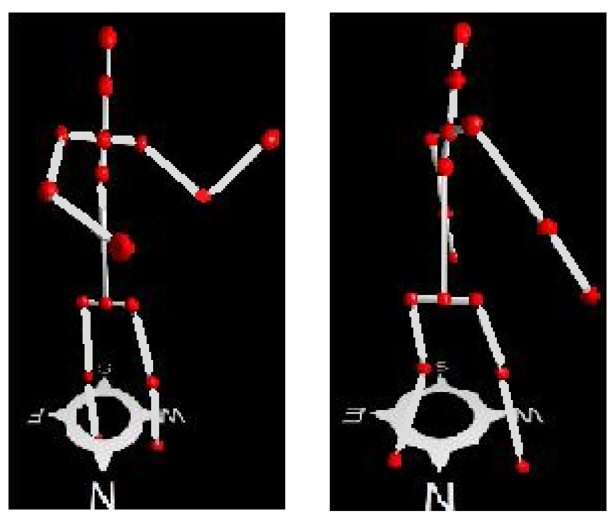
One is interested in the *variation,* δ*,* of the angle between successive frames, t and $t+1$:

$$\delta_{CF} = \theta_{(t+1)} - \theta_{(t)}$$

Clearly a low variation in this measurement would indicate good synchronisation between consecutive frames. This would also constitute an example of good Tango practice, which dictates that movements should be smooth and that dancers should have full control of their steps. Novices are prone to such errors leading to loss of balance or incorrect execution of certain steps, which would be reflected in this metric.

D. Measurement of the angle between the chests

This feature is concerned with how the two dancers rotate with respect to each other. As in the previous two cases, the chest angle will be used once again to obtain estimates of the relative rotations.



Figures 3a-3b: Visual models of a dancer with zero chest rotation (left figure – facing north) and a dancer with a counter-clockwise rotation of 90 degrees (right figure – facing west)

If $\theta 1$ is the chest rotation, with respect to the North, of the first dancer, and $\theta 2$ is the rotation of the second dancer, then the *chest-parallel angle difference,* $\delta\theta$, is the difference between the two angles.

Since the Tango involves close contact and co-ordination between the two dancers, an ideal angle would be around 180 degrees. In this case, the two dancers will be directly opposite each other, and capable of responding quickly to changes in the direction of their partners. An accurate evaluation of this feature would also demonstrate the leader's ability to lead his follower, and whether his movements can be followed by his partner.

E. *Chest movement correlation*

Another feature in the Tango is the correlation between the chest movements of the two dancers. To get a reliable estimate of this metric, the *distance* between the chests of the two dancers is required to be estimated. However, an approximation of the distance is the relative orientations with respect to a fixed point. The chest angles are employed to obtain a *relative estimate* of how the movements of the two dancers correlate.

Figure 2 shows how the chest angles of the two dancers are estimated, by first computing the vector connecting their waist to their chest. Note that the methodology used here is identical to the one described in Section 2.2, where an orthogonal triangle is constructed and used to compute the chest angle. However, compared to the simple chest-bend metric, in this case one is interested in the *variation* of this quantity over time. In a given time frame, the difference d between the two chest angles $\theta 1$ and $\theta 2$ is calculated. Note that this is different from the parallel angle difference estimation discussed in Section 2.4, as this metric compares the chest bend angles rather than the parallel rotation angles of the two dancers. By tracking this quantity over time, one is able to compute the *variation,* δd, of this difference between successive time frames t and $t+1$:

$$\delta d = d_{t+1} - d_t$$

This value is an indication of how synchronised the motion of the dancers are at the chest. A small value δd would indicate good co-ordination between the two partners, while also signaling an ability of the follower to follow the movements of her leader.

IV. Motion Data Capture And Analysis

The Project Management feature in MotionViewer enables several motion capture “takes” to be amalgamated as a project. Each take of the dance performance can have its own set of Orient devices, complete with their own calibration data and joint mapping. Joint mappings can be changed after captures are completed allowing mistakes to be easily corrected.

A real-time Open-GL visualisation of the body-model is provided which enables the capture performances to be monitored. The full 3-D model is viewable with the performer able to move freely around the body to inspect the dance from different angles.

The Plugin API allows the MotionViewer application to be extended. Two types of Plugins are supported: Live and Export. Live Plugins run all the time, even during live motion capture, whereas Export Plugins allow for high-speed, off-line export of motion capture data for use in other applications. Plugins are given access to the body model and are free to manipulate it. A generalised annotation mechanism allows for Plugins to add data to the model without requiring sub-classing of the main software. Annotations can be used to pass data between Plugins. Examples include a Live Plugin for real-time data graphing, which allows sensor data such as acceleration to be monitored along with the 3D model, and a BVH Export Plugin, for integration with existing animation software, such as Motion Builder [15]. A *graphing plug-in* displays the captured quantities graphically, which creates charts that are updated in real time, producing the latest estimates for the tracked quantities (Figures 6-8).

The *performance evaluation plug-in* gives graphical summary of the performance of the dancers for the different dance features – a screenshot of a particular instance is given in Figure 5. A *gradient coloring scheme* is used for easy interpretation in which the extremes range from green (indicating good execution of a given step) to red (poor execution).

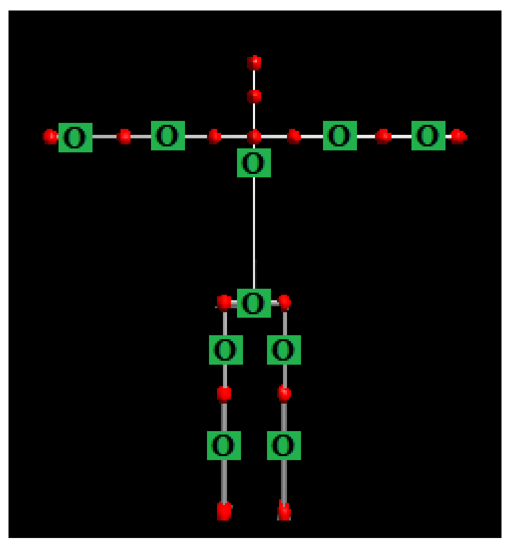


Figure 4: Placement of 10 Orient devices on a Tango dancer (joints are in red, and devices are in green)

Tango dancers can get immediate feedback after a performance on the different features. In addition, the motion capture software has the capability of storing the

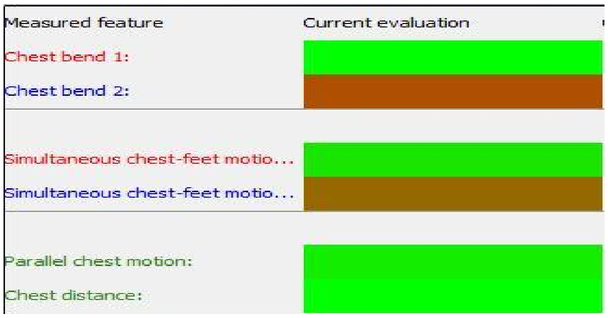


Figure 5: Performance evaluation plug-in

captures, and the dancers can track improvements with practice over time.

A. Results

The results in this section are based on motion capture sessions involving intermediate-level dancers from the Edinburgh University Tango Society. A set of 10 Orient devices was strapped on each person, and their placement on each dancer (in green) is shown in Figure 4.

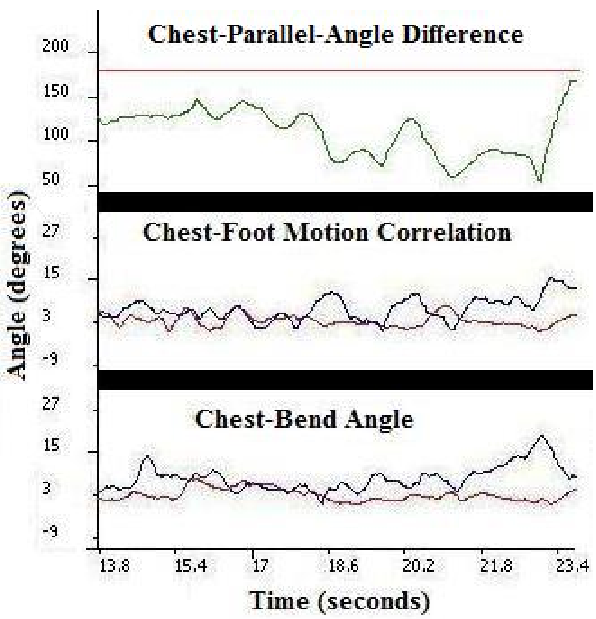


Figure 6: Metrics – 1st interval at the start of the dance

The metrics displayed in the three graphs (Figure 6-8) are the parallel-chest-angle difference, the chest-bending angle and the Chest-Foot Motion Correlation of the dancers. The three graphs display distinct 20-second intervals of the dance at the start (Figure 6), in the middle (Figure 7), and at the later stages of the dance (Figures 8).

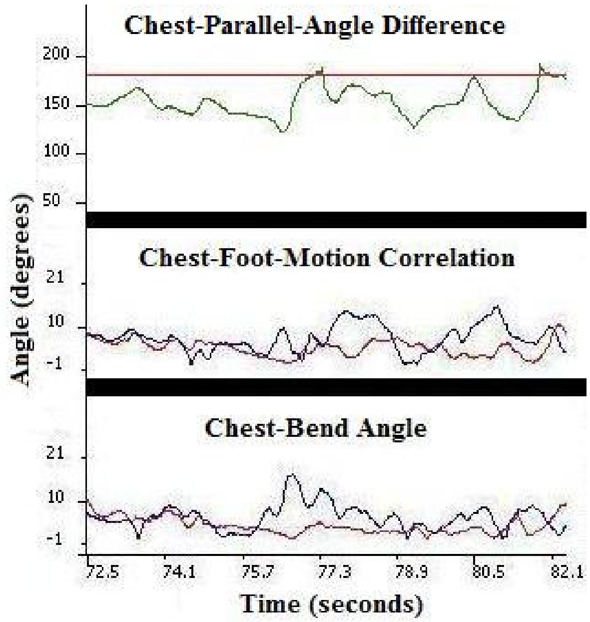


Figure 7: Metrics – 2nd interval in the middle of the dance

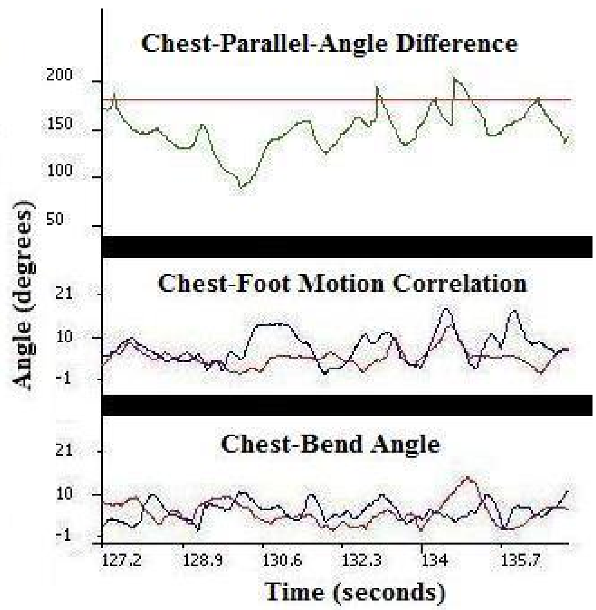


Figure 8: Metrics – 3rd interval towards the end of the dance

By comparing the captured results in each interval, one can identify salient patterns in the dancers. In the case of the "chest-parallel-angle difference" the input values were compared against the recommended value of 180 degrees. In this dataset, one can observe an improvement in the co-ordination of the partners over time. In the first interval (Figure 6), one observes a high deviation from the target value, as angle values are consistently lower than 150 degrees.

In the second interval (Figure 7), the chest parallel angle difference is consistently closer to the optimum with no values lower than 100 degrees are observed. The third interval contains the highest number of intersections with the ideal line, even though the local minimum below 100 degrees at the start of the interval brings the overall performance down. The dancers therefore appear to be capable of identifying mistakes in this aspect of their motion and correcting them accordingly over time.

Measured feature	1st int.	2nd int.	3rd int.
Chest-Bend 1	7.17	6.52	4.98
Chest-Bend 2	2.47	4.36	4.57
Chest-Parallel	6.04	8.53	8.26

Figure 9: Overall performance evaluation per interval

Figure 9 shows the overall evaluation of the performance of a pair of dancers during each of the three intervals. Each feature is assigned a score out of 10, based on the average performance over the given interval. The results on the "chest-parallel-angle difference" metric discussed earlier are also reflected in Figure 9; the computed score is initially mediocre, however in the last two stages the dancers score higher than 8 out of 10 on this feature. Another conclusion that can be drawn is that the leader is more successful in bending his chest (feature "Chest bend 1"), whereas the female dancer (feature "Chest bend 2") scores consistently lower on that metric. Nevertheless, as in the case of the "chest parallel angle difference", the metrics tended to reach an equilibrium, and the discrepancy between the two dancers' scores gradually became smaller. The Chest-Foot motion correlation is consistently better in the case of the leader compared to the follower, with the variations between successive frames being smaller.

V. Conclusion

This paper has described the results for the first deployment of a fully wireless sensor network for a two-person, full-body 3-D motion capture with real-time analysis of three features in Tango dancing. Both individual and collaborative motion features have been used to evaluate the execution of steps, and a score has been defined to evaluate the performance. Three sets of data for periods during the start, middle and later stages in the performance have been presented, with trends identifiable over time in the quality of the dancing. A simple visual icon gives the dancers feedback immediately after the event which could form part of a tutoring tool for Tango. The results have been validated in collaboration with an expert. Future work will follow a cohort of novice dancers in a longitudinal study to track their improvement over several months which will give further insights into the development of a tutoring tool for Tango dancing.

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