Capturing of Contemporary Dance for Preservation and Presentation of Choreographies in Online Scores

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Abstract— **In this paper, we present a generic and affordable approach for an automatized and markerless capturing of movements in dance, which was developed in the Motion Bank / The Forsythe Company project (www.motionbank.org). Thereby within Motion Bank we are considering the complete digitalization workflow starting with the setup of the camera array and ending with a web-based presentation of "Online Scores" visualizing different elements of choreography. Within our project, we have used our technology in two modern dance projects, one "Large Motion Space Performance" covering a large stage in solos and trios and one "Restricted Motion Space Performance" that is suited to be captured with range cameras. The project is realized in close cooperation with different choreographers and dance companies of modern ballet and with multi-media artists forming the visual representations of dance.**

Keywords— Intangible Cultural Heritage, Dance Digitalisation, Motion Capturing

I. INTRODUCTION

Preservation and presentation of cultural heritage is an important societal responsibility requested and supported by UNESCO, but besides digitalization of statues, buildings or paintings, Intangible Cultural Heritage (ICH) assets need to be preserved for future generations. One major form of ICH is dance, but digitization technology for dance presents several research challenges. On the one hand, this relates to motion capturing technologies, and on the other hand to the in situ creation of digital dance representations. Furthermore, the question of how to present, preserve and disseminate dance performances has to be addressed.

Within the MotionBank project (www.motionbank.org), we examined the complete workflow of dance digitalization, starting with motion capturing technologies to be processed in tracking algorithms and resulting in "Online Scores" as digital representations of dance. Thereby, the aim of MotionBank is to transfer the motion capturing data into visual representations of the choreography that on the one hand illustrates synergies/asymmetries in dance performances and that on the other hand transforms motion capture data to online representations of dance choreographies ("Online Scores"). In this sense, our paper details the technologies we used to capture dance performances to be processed in head/body tracking procedures and resulting in visualizations of the "Online Scores". It extends previous work [1] by tracking several dancers and by capturing detailed motion captured data with Kinect cameras. We have realized the dance digitalization of the following performances:

- Large Motion Space Solos and Trios
  We captured and analyzed performances of Deborah Hay's solo "No Time to Fly" (adapted and performed by three different dancers) and of her trio adaptation "As Holy Sites Go". These solos and trios were performed in a wide operation space covering the complete stage with a size of 14 x 14 meters. In our basic setup, we used three camcorders which capture the stage from different positions.

- Restricted Motion Space Duos
  The dance performances of Jonathan Burrows and Matteo Fargion used an operating space of about 8 m^2, sometimes complemented by elementary stage props like chairs/tables or musical instruments. Because of this limited operation space, we realized a multi-camera setup of two Kinect cameras combined with five 2D/HD camcorders.

To present our work, we have structured our paper into the following sections: Section II gives an overview to related work in the field of dance digitalization and motion capturing, while Section III lists the requirements for motion capturing of dance. Section IV details the motion capturing approaches for the "Large Motion Space Performances", using 2D camcorders to record and analyze dances choreographed by Deborah Hay. Section V focuses on the use of range cameras used for the "Restricted Motion Space Performances" capturing Jonathan Burrows' and Matteo Fargions' choreographies. Then, Section VI describes the online score "Using the Sky", which presents the captured and analyzed dance performances of Deborah Hay's solo "No Time to Fly". The corresponding trio adaptation "As Holy Sites Go" is being is being prepared to present on line at a later date. Finally, Section VII summarizes results and discusses future works related to dance capturing.

II. RELATED WORK

Digitalization of modern dance is not only addressed in research for ICH preservation, but it is also an aspect of art investigated by several contemporary choreographers and their dance companies [2][3][4][5]. In this context, William Forsythe and The Ohio State University realized the project "Synchronous Objects" (www.synchronousobjects.org) [6]. The idea of this project was to extract choreographic building

blocks, to quantify them, and to repurpose this information visually and qualitatively. Thereby, the dances have been captured in top and front view. The dances have been interactively marked by animators with the aim to track their movements. On the captured video, different patterns have been identified and have been linked to attribute data as cues (here, it was noted when a dancer is giving a cue for another dancer to move and who is receiving it) or alignments (identified motion patterns). The result of this project is not only the preservation of the choreographic concepts and of the dance performance in digital media; the project also opens choreographic concepts and ideas to anyone interested in contemporary dance. However, the manual and interactive work in the Synchronous Objects is very extensive and thus, within MotionBank, we are researching in motion capturing technologies with the aim to contribute more tractable automatisation to the dance digitalization workflow in the future including the motion capturing.

High-end motion capturing solutions can capture human movements with a high accuracy and reliability [7][8]. While marker-based motion capturing technologies have technologically come to maturity and are successfully used e.g. for the biomechanical analysis of movements [9], they have the drawback that markers need to be attached to the tracked person which is not applicable in modern dance as it requires special preparation and modeling tasks. Moreover, the attached markers can influence the natural movements of the dancer. That is the reason why many different research groups are working on marker-less motion capturing technologies [10]. In this context, active methods like time-of-flight, phase shift and structured light scanners offer high potential that deliver besides the video image a depth map of the captured environment [11][12][13]. The most popular range camera used in this context is the PrimeSense Kinect system [14] [15], as it is used within the Microsoft Xbox and as it is available in the low price range.

III. REQUIRMENTS OF DANCE CAPTURING

Within Motion Bank, we focus on marker-less tracking technologies, that are not restricted to a specific setup and which are easily reusable for other performances or for different stages. Therefore, the goal of our research is to provide solutions based on low-cost, modular and scalable technologies that fulfill the following requirements:

- Scalability and Adaptability
  Within MotionBank, we develop a generic approach which is not restricted to a particular stage (e.g. a stage that is prepared like a blue box used in movie production). The camera setup should be adaptable to other stages and different scenarios. This is of particular importance for capturing modern dance as here the movement space varies strongly for different choreographies and can range from few square meters to large stages with a size of 40 x 30 meters.

- Affordability and Scalability
  Within our projects, we are using commercial off-the-shelf devices with the aim to ensure the affordability of the capturing hardware; our setup is based on default
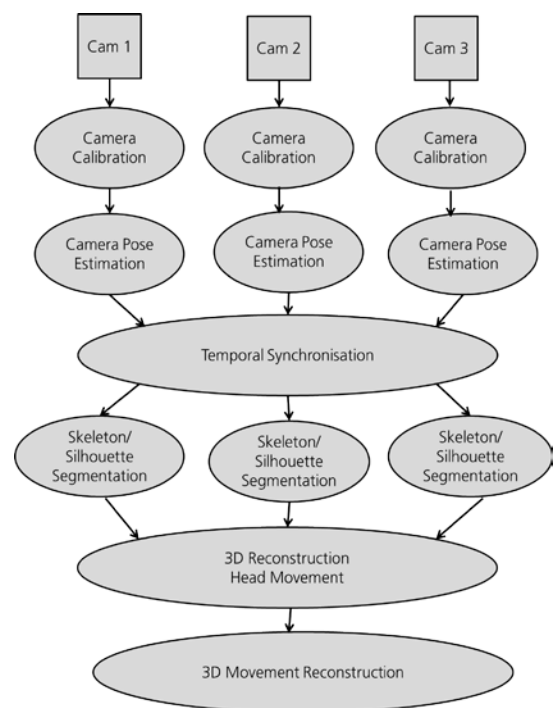

Fig. 1: Image processing workflow of the camera recordings (large motion space).

video camcorders. Our solution scales with an arbitrary number of cameras.

- Markerless capturing, no sensors attached to dancers Motion capture suits (as well as other sensors attached to the human body) hinder the natural movement of dancers. Therefore, we thoroughly focus on markerless motion capture technology for capturing the movement of dancers without disturbing the dancers' moves.

IV. LARGE SPACE SOLOS AND TRIOS

In April 2011, we recorded "No Time to Fly", a dance solo choreographed by Deborah Hay and performed by Janine Durning, Juliette Map and Ros Warby. These large space solos were recorded with three camcorders which capture the stage from above the point of view of the audience (one camcorder on the left, one centered and one on the right). In September 2011, these performances were complemented with recordings of Deborah Hay's trio adaptation "As Holy Sites Go". In order to analyze and interpret the captured data, we processed the camera recordings following the workflow shown in Fig.1. The results of these analyses were used to create the online score "Using the Sky" described in Section VI. The processing workflow includes the following steps:

- Intrinsic Camera Calibration
  An important requirement for 3D-reconstruction of the dancer`s movement is that the intrinsic parameters have to be adjusted for the three cameras. We use a pinhole camera model with additional image undistortion. Therefore, for each camera, we record a sequence of a chessboard calibration pattern held close to the camera. Then, we the focal lengths, the principal

Fig. 3: Use of spherical markers for estimation of the camera poses in relation to each other.
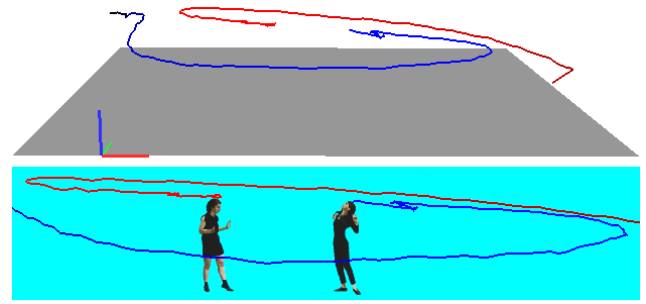

Fig. 2: Silhouette segmentations and 3D movement paths of Jeanine Durning (red) and Ros Warby (blue) performing Deborah Hay's trio "As Holy Sites Go". The world coordinate system at the grey 3D stage representation has a size of 1m.

points and the undistortion parameters are calculated by analyzing the projection of the chessboard calibration pattern onto the camera images [16].

- Camera Pose Estimation
  To calculate the pose (position and orientation) of the three cameras, a set of 2D-3D correspondences is required. Each 2D-3D correspondence contains the 3D position of a point in the world, as well as its 2D projection onto the camera image. In order to robustly estimate a camera pose, the 2D-3D correspondences should cover a large area of the 2D camera image. Therefore, we evenly distribute spherical markers on the whole stage. The markers are composed from several nested circles, such that the center of the pattern is easily detectible from an oblique point of view (c.f. Fig. 2). The positions of the marker centers are measured with a 1D laser scanner and the camera poses are estimated from the 2D-3D correspondences between the 3D marker centers and their projections in the 2D camera images [17].

- Synchronization of the video streams
  The captured video streams were synchronized with a filming clapboard, by detecting the frame in which the clap sticks are shut, and by a QR marker encoding the system time for global timing synchronization. We decided not to use hardware triggering for the camera synchronization, because this would require installing trigger hardware and cables all around the stage. Furthermore, only cameras could be used which have built-in trigger capabilities. Thus, for example, this approach could not be extended to Kinect depth cameras (as used in the restricted motion space setup described in Section V).

- Skeleton and Silhouette Segmentation
  The video analysis provides the basis for web based dance visualizations, e.g. by significantly reducing the required amount of storage by the factor 50-300. The main data reduction is achieved by extracting the silhouette of the dancer from the captured 2D images: While each HD image has a resolution of 1920x1080 pixels, the bounding box around a dancer typically only has a size of about 200x200 pixels. The view of the dancer on the stage can be recombined from the silhouette and a background image of the empty stage. Fig. 3 visualizes colored dancers' silhouettes extracted from a recorded performance of Deborah Hay's trio "As Holy Sites Go". The image pixels which form the silhouette of the dancers are identified by background subtraction. First, a background model (storing the mean and the variance of each pixel's color) of the stage is learned from several images of the empty stage. These images are recorded before the dancers enter the stage. Then, for each pixel of each new camera image, the color value of the pixel is compared with the mean and the variance of the background model in order to decide whether the color difference is significant enough to interpret the current measurement as a foreground pixel. Then, a connected-component merging is applied to find the largest connected segment. All other foreground pixels are discarded. The background model is updated continuously in order to account for lightning changes.

- 3D head tracking
  For estimating the 3D movement path of a dancer, the uppermost position of the head is tracked in the recorded video sequences. To calculate the 3D position of the dancer's head, the head needs to be tracked in 2D in the video sequences of at least two cameras (detecting the head in more than two camera images increases the accuracy). The head can be tracked more robustly than the upper body (especially, if the dancers wear unicolored clothing as in Fig. 3) and more stable than the feet (due to shadows of the dancer on the dance floor). The easiest way to approximate the uppermost position of the head in a 2D camera image is to assume that the uppermost point of the silhouette of the dancer is the uppermost position of the head. While this approach can be used for most captured images, it fails if the head is not the uppermost part of the body (e.g. if a dancer lifts an arm above the head) or if the head is occluded, for example by another dancer. To account for these situations, we combine the tracking of the uppermost silhouette point with adaptive 2D feature tracking. Therefore, a 2D image patch centered on the head is detected in each frame.

This detection is performed by conducting a local search in the proximity of the 2D image patch found in the previous image. The confidence of the detected 2D image patch is evaluated by comparing the detected 2D patch with the reference patch. If the confidence is too low, the 2D feature patch is either adjusted to the altered appearance of the tracked feature, or the tracking stops if a manual re-initialization is needed. If the head is occluded, the feature based tracking can be stabilized by enlarging the 2D feature patch such that it includes the whole body of the dancer. However, when the head is visible, tracking is more stable if the size of the 2D feature includes only the relevant part of the head (because the pose and thus the shape of the dancers can vary strongly while they perform the dance).

- 3D motion reconstruction

  After estimating the position of tracked body parts of the dancers in the 2D images, the 3D positions of the tracked body parts are reconstructed by triangulation. Given the view rays from at least two cameras (which intersect the 2D positions of the tracked body parts in the 2D images), the 3D position of the tracked body part is reconstructed by calculating the closest intersection of the view rays. In addition to the extracted silhouettes, Fig. 3 visualizes a snapshot of two dancer's 3D movement paths while performing Deborah Hay's trio "As Holy Sites Go". The top image shows a top view of the 3D path and a coarse representation of the 3D stage while the bottom image shows a detail of the background subtracted image of the central camera, with the 3D paths projected back onto the 2D camera image.

V. RESTRICTED MOTION SPACE DUOS

In May 2012, Jonathan Burrows and Matteo Fargion performed selected parts of their performances "Both Sitting Duet", "Speaking Dance", "Counting to 100", "The Quiet Dance", "The Cow Piece" and "Cheap Lecture" at the LAB of the Forsythe dance company in Frankfurt, Germany. Within these dance performances, Burrows and Fargion used an operating space of about 8 m^2, sometimes complemented by elementary stage props like chairs or musical instruments. Because of this limited operation space, in addition to the camera array described in section III, we used the PrimeSense Kinect range camera for motion capturing. Thus, we have realized a multi-camera setup of two Kinects and five 2D/HD camcorders. The first Kinect was used to capture the movements of Jonathan Burrows, the second one to capture the movements of Matteo Fargion. Two 2D camcorders were used
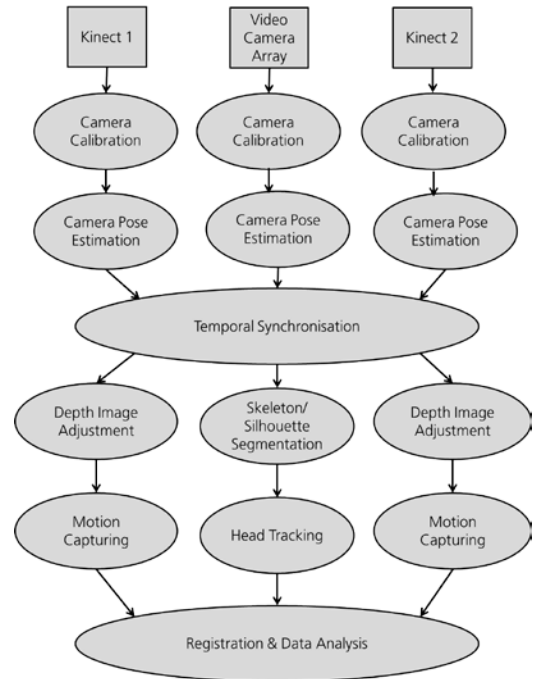

Fig. 4: Image processing workflow (restricted motion space, with Kinects).

for HD close-ups of both Jonathan Burrows and Matteo Fargion. The other ones were used to capture sequences of the whole stage. Fig. 4 shows the processing workflow of the restricted motion space. In this chapter, we focus on a description of the processing of the Kinect data, as the three camcorders capturing sequences of the whole stage were used the same way as described in Section IV. The restricted motion space camera setup is shown in Fig. 5

A. Recording Time Synchronization

In contrast to the 2D cameras, the Kinect cameras capture sequences with varying frame rates. Therefore, the sequences recorded with Kinects are not automatically synchronized in time if the captured videos were synchronized at a single time instance. However, the recordings can be synchronized using the time stamp which is stored with each captured image. Therefore, we synchronize the Kinects the same way as the 2D cameras: to synchronize the capturing, we use a classical clapperboard, in combination with a QR code which encodes the current date and time (in milliseconds) of a reference system. A short video of the QR code displaying the reference time was captured with each camera (see Fig. 6). By detecting the QR code in the captured videos, all recordings were aligned to the common reference time.
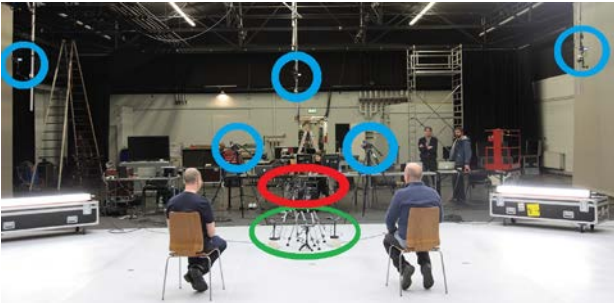
Fig. 5: Camera setup for capturing dances of Jonathan Burrows & Matteo Fargion (May 2012). Blue: 2D camcorders, red: Kinects, green: microphones.

Fig. 6: QR code used for camera synchronization.

Fig. 7: Top: Matteo Fargion, "Both Sitting Duet". Bottom: Jonathan Burrows, "The Cow Piece".

B. Motion Capture Results (Without Occlusions)

We use the Kinects for capturing the motions of the whole body [18]. Fig. 7 visualizes Kinect motion capture poses of Jonathan Burrows, estimated with the Microsoft Kinect SDK. In the dance "Both Sitting Duet" (shown in the upper row of Fig. 7), Jonathan Burrows and Matteo Fargion perform the dance while sitting on a chair. The Kinect SDK offers both a "default" and a specialized "seated" tracking mode. The human poses are estimated with a machine learning approach that was trained with a large set of example images. The main difference between both modes is whether the legs are tracked or not: the "default" mode was trained mostly with reference poses of standing persons, performing different movements. In contrast to the sitting mode, all joints (including the legs) are tracked in the default mode. We initially assumed that the movements of the "Both Sitting Duet" could be tracked more accurately in the seated mode of the SDK. However, we tested both modes and the skeleton tracking was much more accurate in the default mode. Tracking the whole body seems to have a stabilizing effect on the overall motion capture accuracy, also on the accuracy of the estimated poses of the upper body. This is why we consistently used the default Kinect skeleton mode to capture the movements

C. Motion Capture Results (With Occlusions)

The preservation of Intangible Culture Heritage assets requires approaches that are able to capture human poses in spite of occlusions. For instance, Jonathan Burrows performs the dance "The Cow Piece" while standing behind a table (see Fig. 7, bottom). As occlusions pose a major difficulty for motion capture algorithms, we experimented with different filming setups for minimizing the effects of the occlusions. The goal of these evaluations was to find to which extent occlusions can be handled by a suitable filming setup. Our evaluation
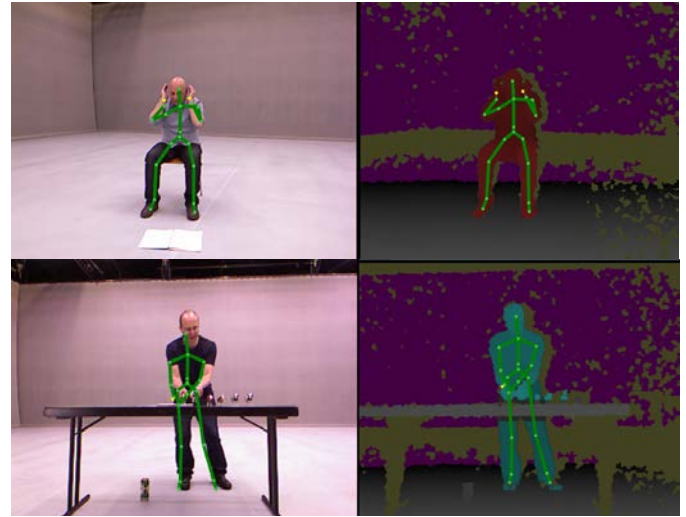
showed that, even in spite of the partial occlusion, the skeleton estimation is very stable if the Kinect is positioned such that the occlusions are minimized. In order to reduce the occlusions as far as possible, we positioned the Kinect such that it records the depth parallel to the table. We found that the major key for a stable motion capturing of the legs is the visibility of the knees. As long as the knees are visible, the pose can be estimated robustly, even if other parts of the legs are occluded.

The dance "Cheap Lecture" poses an example for a different challenge for the skeleton tracking in view of occlusions: In this dance, Jonathan Burrows and Matteo Fargion hold a sheet of paper in front of their body. In some frames, the Kinect skeleton tracking mistakes the sheet of paper for the arms and thus cannot estimate the arm positions correctly. With the Microsoft SDK, it is not possible to change the depth image before the skeleton tracking is estimated. It is only possible to use the skeleton tracking with Microsoft's proprietary .xed format. As this format cannot be loaded or stored other than with the KinectStudio, it is not possible to alter recorded data before it is used as input for the motion capture estimation (KinectStudio is closed source and the specification of the .xed format is not publicly available). Such a sequence adjustment of the recorded depth images would provide the possibility to enhance the accuracy of the skeleton pose estimation with self-written algorithms. For example, the sheet of paper which occludes a dancer could be detected and each depth measurement in this part of the depth image could be replaced with an approximate estimation of the distance of this pixel to his upper body. This would make it possible to track the poses of arms in spite of a sheet of paper or another object which is held by the artist.

As it is not possible to correct occlusions or other obstacles that hinder accurate pose estimations with the Microsoft SDK, we have implemented such approaches (which change the depth image before the skeleton is estimated) with the OpenNI Kinect framework. With these depth image adjustments, it becomes possible to track the poses of dancers in recorded sequences that cannot be correctly analyzed otherwise. For instance, we recorded a performance of Deborah Hay's solo

"No Time to Fly" on a large stage and recorded the dancers' movements with a hand-held Kinect depth camera. Then, we algorithmically detected the ground floor and the background walls in the recorded depth sequence, in order to remove these background 3D measurements from the recorded depth images. Then, we applied OpenNI's skeleton tracking algorithms on the changed depth sequences. Whereas it was not possible to estimate the skeleton of the dancer in the original file, this became possible with the new file that contained the changed depth images. Furthermore, we compared both state-of-the art approaches for capturing movement data with a Kinect (OpenNI and the Microsoft SDK) in view of their suitability for capturing dancer's movements. When the recorded depth sequences do not need to be adjusted, the Microsoft SDK provides a more stable and a much more accurate motion capturing than the OpenNI framework. Thus, except for those sequences which were captured with a hand-held Kinect and which thus needed to be adjusted, we used the Microsoft SDK for capturing the movement of the dancers.

D. Data Analysis: Detection of movement sequences

In order to gain further insights on the captured motions, we algorithmically analyzed the captured data. One characteristic which is common to a broad range of intangible cultural assets, such as dance, is the repetition of characteristic movement patterns or phrases. Such movement patterns are often repeated several times within a dance, either exactly the same way or with temporal or three dimensional movement variations. However, the manual detection of all occurrences of a specific movement pattern is a very time consuming task. Manual detection is likely to always be necessary at certain scales, but the time required for analysis can be less if algorithmic approaches which automatically detect similar subsequences in recorded video streams can be used. Therefore, we have developed algorithms that automatically detect similar movement subsequences and we have applied these algorithms on the recorded dances.

To find identical or similar subsequences within a recorded sequence that correspond to a certain movement pattern, the user first specifies a set of key frames which represent characteristic poses of the searched movement pattern. Furthermore, if required, the feasible timing variance t can be specified: for any subsequent pair of frames corresponding to a pair of key frames, the duration between the frames must be at least 1/t and may be at most t times the duration between the key frames. In a next step, the recorded sequence (or a set of recorded sequences) is processed in order to find subsequences that contain all requested key frames, in the same order as specified by the key frame sequence.

The Kinect motion capturing provides estimated joint positions for 20 different joints (hip, spine, shoulder, head, elbows, wrists, hands, knees, ankles and feet). However, the joint positions of two frames are not aligned. For example, if the dancer turned during the performance, the arms and legs are at different 3D positions. Therefore, in order to compare the similarity of a human pose from a key frame with the human pose of another frame, the skeletons of the key frame and the skeleton of the evaluated frame need to be aligned. To align the estimated poses of two skeletons, we first create pairs of
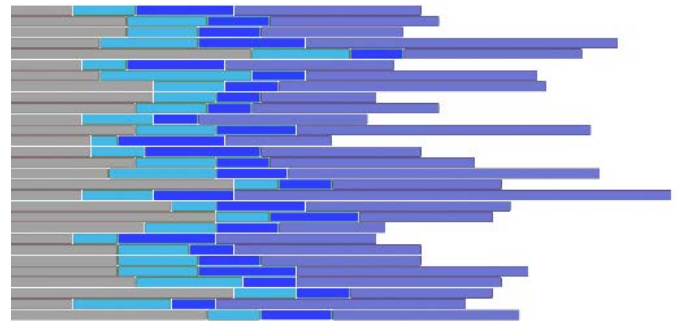

Fig. 8: Timing variations of the same movement pattern performed several times.

corresponding joints and align the centroids of the point pairs. Then, we calculate a rotation which aligns the orientation of the point pairs by minimizing the average distance between the pairs with singular value decomposition. After the two skeletons have been aligned, we calculate the similarity of the poses by the average Euclidean distance between each pair of corresponding joint positions. In order to account for movements where only the poses of some body parts matter, both the alignment and the similarity estimation can be restricted to these body parts. For example, if a dancer performs a hand clapping sequence, the similarity estimation is restricted to the upper body and the arm positions, while the poses of the feet are not taken into account. This increases the robustness in view of movements which are not relevant for the movement at hand.

We applied the automatic detection of similar movements on the Jonathan Burrows & Matteo Fargion Kinect recordings from May 2012. Using the described approach, we algorithmically detected varying occurrences of characteristic movement patterns. The detected subsequences were added as annotations to the recorded video sequences. This contributes to three main tasks:

1. Such annotations support users to gain information and understanding about the dance.

2. These annotations ease the processing of the recorded data. For instance, during the recording session which took several days, we recorded several takes of each part of every dance. The automatic detection reduces the time it takes to process all the recorded data, such as the task to find all occurrences of a certain part of a dance in order to select the best recording for publication of the recording on the final website.

3. Such an automatic detection provides the means to analyse the movements algorithmically, for example in terms of recurring patterns, in terms of changes and in terms of variances.

As an example, Fig. 8 illustrates the timing variances of a movement pattern defined by four different key frames. Furthermore, we use the detected subsequences to provide the possibility to recompose the recorded movements. Thus, in some way, one can become a choreographer oneself by recomposing recorded patterns to create a new dance. The processed Burrows/Fargion recordings will be published
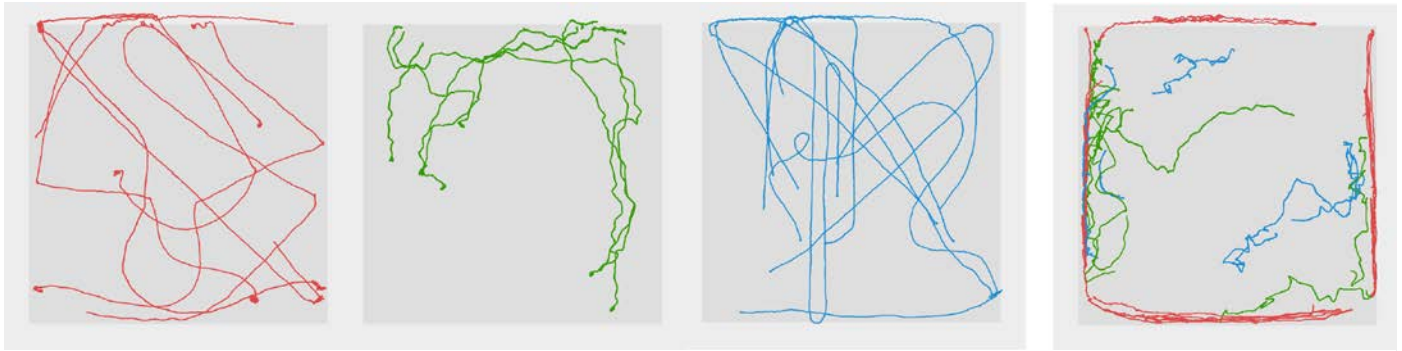
Fig. 9: Movement paths of Janine Durning (red), Juliette Map (green) and Ros Warby (blue) performing the same part of Deborah Hay's solo "No Time to Fly" seven times. The first three images show the movement paths of the same part of the dance and the forth image shows the movement paths of another part.

online at the final MotionBank release event in November 2013.

VI.   ONLINE SCORE: "USING THE SKY" (DEBORAH HAY)

The MotionBank research results are published online at three dedicated websites, one per guest choreographer (by Jonathan Burrows & Matteo Fargion, Bebe Miller & Thomas Hauert and Deborah Hay). In June 2013, a beta version of "Using the Sky", the website which presents performances of Deborah Hays' choreographies "No Time to Fly" and "As Holy Sites Go", was released online at http://scores.motionbank.org/dh/. This website has been created by Motion Bank's digital artists, forming the visual representations of the dances. This section describes some of the concepts and visual representations of the "Using the Sky" online score.

An important aspect of Deborah Hay's choreographies is, in contrast to classical dance, that they have no explicit detailed formulation of predefined movements. Instead, Deborah Hay emphasizes: "History choreographs all of us, including dancers. The choreographed body dominates most dancing, for better or for worse. The questions that guide me through a dance are like the tools one would use for renovating an already existing house. Like a screwdriver being turned counter-clockwise, or a crow bar prying boards free from a wall, the dancer applies the questions to re-choreograph his/her perceived relationship to him/herself, the audience, space, time, and the instantaneous awareness of any of these combined experiences. The questions help uproot behavior that gathers experimentally and/or experientially. […] I recognize my choreography when I see a dancer's self-regulated transcendence of his/her choreographed body within in a movement sequence that distinguishes one dance from another." [19].

Thus, even if a dancer performs several takes of the same piece, starting points, positions on stage and movements change, although there is still a perceivable structure. In order to increase comprehension, the online score integrates information from very different kinds of knowledge sources. On the one hand, the recordings of 21 instantiations of the solo adaptation "No Time to Fly" (performed by Janine Warning, Juliette Map and Ros Warby) are published at the online score.

Each dancer performed the solo seven times. Furthermore, each subsequence of the dance is linked

- to the text of the written score which describes the current part and
- to interactive data visualizations of the analysed movement data.

The visualizations of the movement paths and of the visual hull illustrate how the dance took place spatially throughout time. Thus, these visualizations illustrate how the same part of the written score is instantiated per dancer (intra-personal) and among all three of them (inter-personal). The movement paths of each dancer reveal that each dancer has a very personal way of expression that gives each dance some kind of style or signature, which doesn't become as obvious, when watching the real performance without the additional visualizations of the analysed movement data. These characteristics emerge upon the dancers' choices in relation to location and space.

The first three images of Fig. 9 show movement paths which are performances of the following description from the written score: "Light returns and I am tiptoeing, not wanting to disrupt the space already created – a task I hold in high regard. I experience space parting, with little to no disturbance, hoping that the audience will see this too, before arriving somewhere that is not center stage. My actions are obvious. When I imagine the stage is still, instantaneously perform my almost non-existent fake American Indian ritual dance which I may be the only person in the world to realize. Punctuated by beating drums that only I can hear I may bounce rhythmlessly with the supposed drums." Similarly, the forth image of Fig. 9 shows the movement paths of the following description in the written score: "I perform counterintuitive travel somewhere at the edge of the space. A cranky voice provides continuous accompaniment". Fig. 10 shows the space of the stage used by each dancer while performing two different parts of the dance. The combined and linked views of several dances performed by three different dancers, the analysed data and the corresponding choreographic description from the written score provide insight into the choreographic and artistic work, which is furthermore complemented by interviews in which Deborah Hay and the dancers provide insights about their concepts, the performances, the research and the choreography.
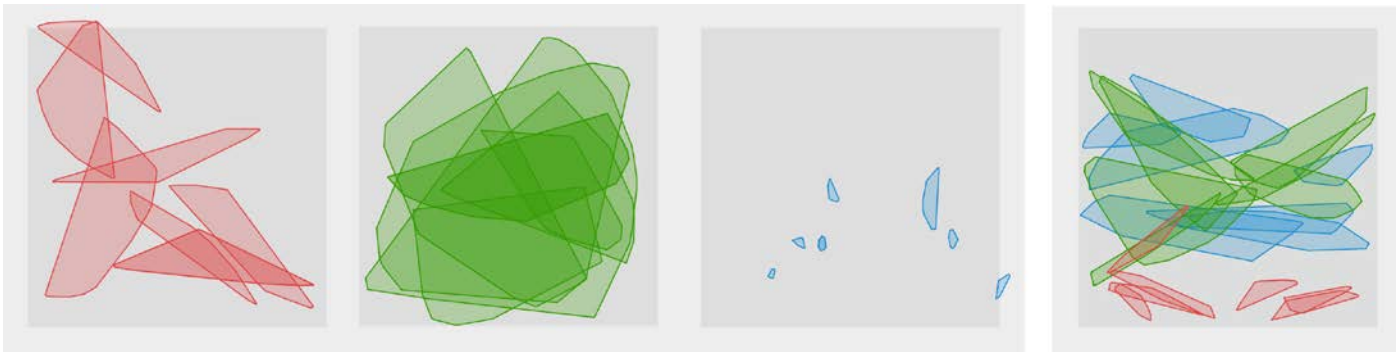
Fig. 10: Convex hull of movement paths of Janine Durning (red), Juliette Map (green) and Ros Warby (blue) performing the same part of the dance seven times. The convex hull shows the space of the stage that is used during the performance of the sequence. The first three images show the space used during the performance of the same part and the forth image shows the space used by each dancer, performing another part of the dance.

VII. CONCLUSIONS AND FUTURE WORK

Within our paper, we have presented a workflow for the digitalisation of dance that has been applied in two productions of modern ballet. The first of these productions (the dances choreographed by Deborah Hay) has been published in form of the Online Score "Using the Sky". The dances of Jonathan Burrows and Matteo Fargion will be published online in November 2013. The approach described in this paper is scalable and it can be adapted to different sceneries by using 2D camera arrays linked to 3D range cameras. The MotionBank project not only focuses on the digitalization of dance: its aim is as well to analyze and visualize choreographic elements like patterns or cues. Thus, the results of the motion tracking have been processed to be visualized in multimedia art broadcasted via the web.

So far (from the technical point of view), we have been lucky that our chorographers arranged solos, duos and trios, as with a growing number of dancers, the motion tracking gets much more complex. In this sense, in future work, we want to focus on tracking methods for major groups and thereby we want to improve the performance of the capturing methods. The final goal is to visualize "Online Scores" in real-time and in relation to the captured dance performances in an Augmented Reality manner, with the aim to offer the dance digitalization and visualization as part of the artistic performance.

VIII. ACKNOWLEDGEMENT

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