WhoLoDancE: Whole-body Interaction Learning for Dance Education

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Abstract. Dance resides among the most ancestral forms of art, representing a major asset of the human intangible cultural heritage playing, at the same time, a primary role in contemporary artistic creation. WhoLoDancE, a Research and Innovation Action funded under the European Union's Horizon 2020 research and innovation programme, aimed at the double goal of preserving its inheritance and integrating digital technologies into contemporary dance learning, teaching and choreography through the digitalisation of dance movements with motion capture techniques, the creation of a large motion repository - including movements from ballet, contemporary, flamenco and traditional Greek folk dances - and the implementation of breakthrough applications ranging from movement quality annotation and segmentation, similarity search, movement blending, multimodal and virtual reality-based experiences for self-reflection and experimentation. In this paper, we present the prototype tools and state-of-the-art results of the project development in its conclusive phase, highlighting the added value this interdisciplinary approach could possibly bring to dance learning and practice, the main technical, practical and cultural challenges encountered in this path and open issues to be addressed in the months to come, providing hints on future research directions.

Keywords: Dance, Education, Learning, Motion Capture, Information Technology, Machine Learning, Virtual Reality, Intangible Cultural Heritage

1   Introduction

WhoLoDancE is a three-year Research and Innovation Action funded under the European Union's Horizon 2020 programme (2016-2018), which aimed at developing and applying breakthrough technologies to dance learning to have a relevant impact on dance practitioners including researchers, professionals and dance students.

The project builds around five main interconnected objectives:

1. *investigate bodily knowledge* by applying similarity search tools, computational models and techniques for the automated analysis of non-verbal expressive movement of dance data to help investigate movement and learning principles, vocabularies, mental imagery and simulation connected to dance practises;

2. *preserve the cultural heritage* by creating a proof-of-concept motion capture repository of dance motions, along with built-in methods allowing interpolations, extrapolations and synthesis among different compositions documenting diverse dance movement practices and learning approaches;

3. *innovate the teaching of dance* by developing multimodal experiences and life-size volumetric displays that through immersive and responsive motion capture data can identify and respond to collisions between the physical and virtual bodies;

4. *enrich choreography* by structuring an interactive repository of motion capture dance libraries and providing choreographers and dance teachers a custom dance data blending engine to assemble an infinite number of dance compositions;

5. *widen the access and practice of dance* by providing access to the created dance database through commercially available consumer-grade motion capture devices.

2   WhoLoDancE: an Overview

WhoLoDancE has been conceived as an unprecedented approach to dance, leveraging breakthrough technologies to digitalise, preserve and convey the European intangible dance cultural heritage, and bring a profound innovation in the way this long-standing art is traditionally created, learnt and taught [1]. This has entailed the shared definition of twelve dance movement principles [2], set as an open conceptual framework for the subsequent recording of a wide range of dance movements through the use of motion capture techniques, their annotation and enrichment, and the development of cutting edge algorithms to explore, analyse and re-elaborate this data at the service of dance learning and choreography, together with the implementation of multimodal and virtual body exploration experiences in real time, able to offer dance professionals and practitioners a new way of self-reflection-based experimentation.

To achieve these goals, the project work plan has been articulated in three phases: the former, dedicated to the acquisition of preliminary knowledge and movement data; the second, directed to the definition of expressive movement and music-dance representation models and the preliminary deployment of data-driven and model-driven analysis software; the third one, aimed at the final delivery of data-driven tools and visual interactive user interfaces, their refinement and evaluation by external dance experts.

2.1 Motion Capture, Knowledge Acquisition and Semantic Models

The first project phase has been pivotal for creating the ground knowledge and database on which to build and train our data-driven tools. The Consortium planned three motion capture sessions, leading to the production of a substantial volume of kinetic material representative of the four selected dance genres: ballet, contemporary, flamenco and Greek folk dances. This has been developed alongside the acquisition of preliminary knowledge from end-users, obtained through focus groups and interviews with dance experts inside and outside WhoLoDancE, necessary for a first definition of different users' profiles and use case scenarios. Prior to the motion capture acquisition, dance partners and IT researchers have jointly defined a set of twelve dance movement principles, as the open conceptual framework of the whole approach.

2.2 Prototype Finalisation, Definition of Representation and Learning Models

The second, intermediate phase of activity has been dedicated to the delineation of models for movement expression and music-dance representation, alongside with data-driven and model-driven analysis software. A unique aspect of WhoLoDancE is in fact the variety and diversity of tools that have been created through a cross-disciplinary dialogue, comprising a modular collection of tools for dance practitioners. Among them, the Consortium has finalised its web-based users' interface to access the data repository, further supplemented by an annotator [3], which has been employed by dance partners for manual annotation of motion capture recordings. This process, which consisted of the description of dance sequences in respect to a set of movement qualities agreed between the team of dance experts, has in turn been essential for the development of a variety of applications, including similarity search, movement sketching and multi-modal rendering, and constituted the ground data for the training of machine learning-based algorithms for automatic annotation and segmentation, to be employed for the enrichment of further movement data. The prototype development adopted a co-design process based on a continuous dialogue with dance professionals through workshops and hands-on sessions. This iterative, user-centred approach provided strategic clues for further improvement and the opportunity to reflect on concrete cases before evolving the tools to their next version, also contributing to the definition of the relevant use case scenarios, outlining innovative approaches to dance teaching, learning and choreographic creation.

2.3 Finalisation, Evaluation and Integration

The last phase of the project, currently in progress, is seeing all partners finalising their efforts towards the refinement, validation and integration of the final version of the developed tools into a unique, seamless comprehensive framework, where users will be able to take the best of what has been attained along with defined use-case scenarios. Meanwhile, the Consortium is preparing texts, demo videos and tutorials in view of the upcoming final evaluation of the proposed tools by a community of selected dance experts, drawing on the Consortium's large network of professional

dancers, choreographers, teachers and learners from different dance disciplines. The evaluation will rely on a combination of qualitative and quantitative methods and include web questionnaires - for online users - and live evaluation sessions with one-to-one interviews. These one-day sessions will entail a theoretical presentation of the tools followed by a hands-on practical workshop to allow a thorough assessment of usability, reliability and accuracy of the tools and their added value for the dance community, other cultural heritage research on dance and beyond.

3   A Diversified Consortium: When Art Meets Technology

WhoLoDancE relies on an interdisciplinary team composed of technologists, such as computer scientists, acoustic engineers, 3D animation specialists, and dance experts, including dance researchers, teachers and choreographers coming from different dance specialties. While the former have been responsible for the acquisition and elaboration of motion capture data, the conception and implementation of analytics, software and technologies, the latter have been fundamental for the practical and theoretical dance knowledge they have been sharing throughout the project development, from the production of motion data, passing through the segmentation and annotation of dance sequences and the evaluation of project tools from the users' side. Most importantly, the cooperation between technologists and dance experts has been pivotal for the definition of movement principles, along with the elaboration of use case application scenarios for the implemented tools. The interpenetration of art and technology has represented, though, not a bare mixture of diverse competences, but rather a constant and enriching dialogue between different methods and practises, which have been fertilising, complementing and innovating each other in new directions.

3.1   Computer Science and 3D Animation: the Ground Base of WhoLoDancE

Motion capture technology has constituted the very foundation of the whole project, providing the raw data to model and train machine learning-based algorithms. The very protagonist of this pivotal phase has been *Motek Entertainment*, a performance capture, 3D animation and VR production studio based in Amsterdam. The studio has also been responsible for the implementation of the dance movement blending engine and holographic volumetric display technologies.

Information technology represented the core expertise for the gathering of technical requirements, the development of the data management platform and end-user interfaces. This role has been played by the *Athena Research Center in Information, Communication and Knowledge Technologies* of Athens, which has also been essential for the development of whole-body interaction technologies.

Another strategic aspect of the project has been, in turn, the elaboration of sound, video and movement data into music and dance representation models. This has been achieved through joined efforts of acoustic and software engineers from *Image and Sound Processing Group* of *Politecnico di Milano*, *Casa Paganini-InfoMus* at *University of Genova* and *Peachnote GmbH*, Munich. These researchers have worked

closely to the development of software libraries for the analysis of music and movement kinetic and expressive features, and strategies for mapping of movement qualities into sound and multimodal content; they have implemented and trained algorithms for leveraging and enriching motion capture data, such as similarity search, automatic annotation and beat tracking. These models have been in turn utilised as base for a variety of applications, ranging from search and similarity systems to real-time motion-based applications.

These efforts have been coordinated by Lynkeus, a strategy consultancy specialised in the conception and management of EU-funded projects with a specific expertise on ICT and analytics applications. Lynkeus plays the role of Project Coordinator and has been responsible for science communication and dissemination activities, exploitation and IPR management.

3.2   Dance Education and Choreography: Shaping the Project Framework

WhoLoDancE has brought together representatives of Europe's dance cultural heritage and the most advanced tendencies in contemporary dance, based on the intersection of body gesture and digital arts. The former group includes *Lykeion ton Hellenidon*, a Consultative organization of the UNESCO Intergovernmental Committee for the Safeguarding of the Intangible Cultural Heritage active in the preservation of Greek cultural traditions, a flamenco historian and teacher from the *Centre for Dance Research* of *Coventry University*, and ballet professionals from *Instituto Stocos* of Madrid; the latter involves the contemporary dance company *K. Danse* of Toulouse and Instituto Stocos. These experienced dancers, teachers and choreographers have been primarily responsible for the conception of dance movement principles, the preparation and rehearsal of motion capture sessions and the subsequent annotation and segmentation of the relevant motion capture data; they have been supporting the implementation of project tools through insights and feedback from the user's side and the development of music and dance representation models.

As one of Europe's leading research centers for dance, the Centre for Dance Research of Coventry University has been chiefly responsible for the elaboration of use case scenarios and is leading the evaluation of the project tools, thanks to its broad and varied connection with the dance community at national and international level.

4   The WhoLoDancE Framework

Being in the final year of the project, the Consortium has now finalised a wide range of prototype tools ranging from user interfaces, movement segmentation and annotation, similarity search, multimodal and virtual reality applications (Fig. 1), which are going to be evaluated by a list of selected dance and movement capture experts prior to public release. Most of the tools are web-based, while others, such as Choreomorphy, sonification and the blending engine, are standalone applications, often Unity-based. By the end of the project, the Consortium has envisaged the harmonisation of all applications into a unique solution leveraging all available

functionalities. To this aim, partners are currently working towards the integration of tools into a single, comprehensive framework that will rely on two different access modalities: on one side, a web-based front-end dedicated to low-end, distributed services, freely accessible through any personal device; on the other, a remote access modality taking the Unity 3D™ game engine as core base, which will allow performance of high-end, interactive and immersive applications, available upon licence. This resource is designed to serve all envisaged application scenarios and be further expandable to possible additional ones in the future.

Movement Library and Annotator. The WhoLoDancE movement library (WML) represents a web-based interface to navigate the dance motion repository. A user can browse or search recordings by their associated metadata (*title, genre, annotations, performer, dance company* and *date of recording*) or create personal playlists. A multimodal player allows to watch the synchronized playback of the video and the corresponding motion capture-derived 3D avatar and interact with it, e.g., by rotating the scene to observe the movement from different perspectives. The embedded *annotation tool* enables manual annotation of performances with movement qualities, with a tabular and a timeline view.

Segmentation Tool. This tool is designed for manual segmentation of motion sequences into simpler movement segments. The tool includes a 3D viewer allowing to rotate the scene, zoom in/out and switch to/from full-screen view, a player to follow the execution frame by frame and a tabular view.

Blending Engine. The software is aimed at interactive composition of movement sequences with mocap data available in the library. Sequences can be assembled in a linear setup, i.e., blending movements consecutively in time to form a longer, seamless sequence, or in parallel, i.e., superposing parts of movements to form new movements, e.g., with the leg movement of one sequence and the upper body part of another.

Similarity Engine. This system is able to analyse the representation of a selected movement recording (query) and employ a comparison algorithm to identify the most similar movements in the library, according to user-defined criteria. On this basis, the Consortium has built three derived applications for as many application scenarios:

- in the *similarity search* web-based, desktop application, the user can select a recording of interest in the library as set it as query to search and retrieve the most similar movements in regard to a user-defined 'weighted' template of movement qualities and properties;
- in the web-based *real-time mobile movement search application*, the user is able to record his/her movement through any smartphone camera and use it as the query for similarity search in real time;
- in the *movement sketching* tool, the user can capture his/her movement through low-cost sensors (e.g., xOSC, Notch) analyse it in relation to a selection of expressive movement qualities of choice and search for similar movements, to compare one's motion with the ones of professional dancers in the repository.

Choreomorphy. Choreomorphy is an interactive system that supports reflective dance improvisation through the use of motion capture technologies. By wearing a mocap suit, a user can visualise his/her movements in real time through a 3D avatar and related volumetric trails, with the possibility of switching among different avatars

and settings, facilitating self-reflection and experimentation. The application also allows to load pre-recorded mocap data and watch them in a variety of avatars, environments and effects or even in augmented reality through the HoloLens.

Low-end Virtual Reality Platform. This web-based visualisation layer is designed to watch mocap recordings as an immersive VR experience on a common smartphone and can be placed on top of other applications. The platform supports tracking of head orientation and includes a standard avatar to watch mocap recordings, a system to watch videos on virtual walls and customizable 3D environments.

Sonification Tool. Sonification enables to have a real-time, responsive feedback on different aspects of a dancer's movement without causing distraction. This multimodal tool utilises different sensors (e.g., Kinect V2 cameras, XOSC IMU sensors, MYO sensors) to capture the dancer's movement, while several EyesWeb [4]-based analysis modules examine the dancer's movement and position on stage and stream the extracted qualities to a sonification environment (e.g., supercollider, Max) that maps movement qualities with various elements of sonification in real time.

Fig. 1. WhoLoDancE Framework tools in action: Choreomorphy *(top left)*; low-end virtual reality platform *(bottom left)*; sonification tool *(top right)*; real-time mobile movement search application *(center-right)*, movement sketching tool *(bottom right)*. Credits: Amalia Markatzi.

5 Towards a multidisciplinary approach to dance

Besides reaching tangible technological achievements in the form of software applications and multimodal experiences, the WhoLoDancE approach has contributed to highlight the added value of combining not only information technology into dance, but also a variety of movement practices coming from different dance genres.

Dance represents a highly complex human activity, encompassing intangible cultural heritage and contemporary artistic creation, expressing as an innate and spontaneous social activity as well as a virtuosic art practice and a codified form of academic knowledge. For these reasons, it constituted an excellent testing ground of how technology can provide valuable tools for preservation and documentation of cultural assets such as dance movements, qualities and practices, but it also revealed the challenges and affordances when dance and technology can work together to cross fertilise each other's practices and methods. In this case, scientific approaches enter the digital medium, working closely with different dance genres to establish a mutually beneficial dialogue, highlighting where there are commonalities within different dance practices, and between dance and other disciplines. These commonalities, which are summarized and reflected in the WhoLoDancE conceptual framework, can provide the basis for further application, supporting the teaching and learning of other dance genres, movement practices and offering models that can support engagement with other tangible and intangible cultural forms.

Moreover, by bringing together very varied dance genres, representing very different traditions, such as ballet and flamenco, contemporary and traditional dances, the tools needed to be responsive to disciplinary differences whilst identifying common principles, thereby providing the ideal ground for cross-fertilisation and inspiration, enriching the opportunities for choreographic creation, for contamination across dance genres, and stimulating new methods for teaching, learning and creating dance. Another important dimension of the project that has emerged as pivotal is the opportunity to analyse dance movement in depth from a variety of perspectives, as well as from the user's own position, thereby encouraging self-experimentation, offering alternatives to traditional modes of mimicking approaches to dance learning. For instance, the user has the possibility to watch simultaneously a performance from different perspectives, such as the frontal video and the avatar obtained by mocap recording, as provided in the motion repository. This aspect, as highlighted within focus groups with dance experts, emerged as a valuable method when compared with relying on 2D videos and one perspective cameras only, especially in the field of traditional Greek folk dances, which are performed in a circle, usually with long and heavy costumes which can obscure some of the movement detail. But a major asset, according to dancers from all genres, derives from the possibility of self-reflection, as provided by tools such as Choreomorphy [5], allowing dancers to observe their own movement to generate different avatar shapes and volumetric trails, or sonification, focused on the conversion of movements position and velocity into sound. These tools support learners in observing their own movement and the movement of others in more detail and allow users to play with observing variations in movement qualities, dynamics and spatial properties by accessing different dancing avatars. Such close

readings - of a dancer's own movement and that of others doing same, similar or contrasting movement - may tune perception in new ways, allowing dancers to gain insights into their own dance development from the 'inside' whilst having the chance to make connections with other dance practices that may be otherwise unfamiliar to them [6-7]. The learning thus takes place on a practical level, as well as on a theoretical and conceptual level, providing knowledge about the history, traditions and contemporary renditions of cultural (dance) practices and how digital technologies impact on how these practices are transmitted, learnt and performed.

6 Open challenges

WhoLoDancE represents a pioneering approach to dance, and from its very outset it has posed several challenges: technical, practical as well as cultural.

One major issue has been related to the process of collecting dance annotations from dance experts, which constituted the ground base data for the implementation and training of machine learning-based algorithms for movement analysis, automatic annotation above all. This has required the a priori definition of a set of movement qualities to be agreed within the entire team of experts, followed by a long process of manual annotation of movements in the form of scores ranging from 0 to 10. These, in turn, have been utilised to construct movement ratings in respect to specific qualities. This procedure presented a primary, technical difficulty, as various experts, coming from diverse dance specialties, showed a different - subjective and cultural - perception of movement qualities, such as fluidity or heaviness. This, together with the limited number of individuals involved in the annotation process, made it very hard to reach consensus values required for an effective algorithm training. To balance this subjectivity bias, one of the further steps agreed upon is to open the annotation procedure to a larger community of dance experts and amateurs on the web. This, however, requires a proper re-design and simplification of the annotation tool and the relevant procedure, so as to be straightforward and easy-to-use for professionals as well as non-experts.

Another important, practical hurdle is linked to the cutting-edge technology and hardware on which the implemented tools are based on. This means there is much more to explore in bringing these tools to the everyday life of practitioners, which would require more affordable, portable and less intrusive technologies. This must be done in close connection with the definition of users' needs in real-life settings to harmonise them in the context of the existing dance and learning practices.

Closely related to this point resides the major, cultural challenge of the project, the possibility to integrate the use of technology into dance practice, which is still not perceived as a real necessity by most of the dance community. This necessarily involves the active search for opportunities where to demonstrate the pertinence of the tools through hands-on experiences, such as workshops offered by independent companies, integrated classes at dance and music conservatories, special sessions in dance and technology festivals, dedicated events in art-science conferences and seminars. These would allow dance professionals time to "play" and engage with the

applications on their own terms, outside of the "contained" environments in which they have been presented so far. In this sense, previous evaluative sessions indicate how these are helpful in swaying people's perspective and opinion and inspiring them with the vast potentialities offered by these new tools, even traditional art forms such as flamenco or Greek folk dance. Underpinning the project work is a commitment to work collaboratively across dance and technology, thereby ensuring that the tools have 'real world' benefits to those working in diverse areas of the dance sector.

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