Mova: Interactive Movement Analytics Platform

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ABSTRACT

There is an increasing interest in analyzing, extracting, and representing human movements in terms of a set of spatial, temporal, and qualitative characteristics for applications such as human-computer interactions and sports and health movement analysis. Information visualization techniques can be used to help people better understand the contents of movements. While all the characteristics of movement may not always be visible or detectable by humans, visualizations can illustrate detailed information about the characteristics of the movement. We present the prototype of an interactive movement analytics framework, called Mova, for feature extraction, feature visualization, and analysis of human movement data. Integrated with a library of feature extraction methods, this platform can be used to anaylze movement qualities and investigate the relationships between its characteristics. In addition, Mova can be used to develop and validate new feature extraction methods with the help of parallel visualization of multiple features. We discuss test-cases in which Mova can be used and detail the road-map for its further development.

Link to the platform: `http://www.sfu.ca/~oalemi/mova`

Categories and Subject Descriptors

H.5.0 [**Information Interfaces and Presentation**]: General

Keywords

human movement analysis, movement feature extraction, movement visualization

1. INTRODUCTION

Analyzing and understanding human movement has gained the attention of researchers especially in the fields such as human-computer interaction, computer animation, and sports and health research. Human movement is a form of non-verbal communication which conveys information about its performer. An important aspect of studying human movement is to extract and represent its content in terms of a set of spatial, temporal, and qualitative characteristics such as kinematics (speed, acceleration, and jerk), shape (contraction/expansion of body), the body structure (balance, center of mass, distance between body parts, etc), effort (space, time, weight, flow), emotions, and gestures. These characteristics are then used to interpret the movement and draw conclusions about it. For example, identify the functional, executional, and expressive aspects of human movement, recognize gestures and their qualities, index a movement database, or incorporate encoded movement features into a movement generation model in order to generate new movements based on a set of required features[1].

Movement information are represented in different forms from a simple video recording of the actor to the configuration of joints position (posture), joints acceleration, physiological properties of body parts, breathing, or the gaze of the actor. These information can be recorded from human actors through sensors (motion capture, accelerometer, etc), or be generated using computational techniques. On the one hand, raw movement data provide little information about many underlying characteristics of the movement. Such characteristics need to be determined by human experts, analytical calculations, or machine learning approaches. On the other hand, once the characteristics are determined, a visual representation system is needed to convey these information to others.

Information visualization techniques can be used to illustrate movement and provide more information about its characteristics. Visualizations can be dynamic or static and can represent only the body skeleton or more high-level features of the movement. Movements can be visualized using different techniques ranging from the raw video recording of the actor/performer, the skeletal representation, animation, movement notation systems (e.g., Benesh or Labanotation) to more arbitrary visual representations of movement characteristics.

We present a prototype of *Mova*, an interactive movement analytics platform which is developed as part of Movement + Meaning Middleware project[2] that aims to provide a computation framework for movement information representation and manipulation. Mova is an open-source and web-based

MOCO'14, June 16-17 2014, Paris, France.

ACM 978-1-4503-2814-2/14/06 ...$15.00.
http://dx.doi.org/10.1145/2617995.2618002.

[1]In this paper, we use the terms *characteristic* and *feature* interchangeably.

[2]`http://mnm.hplustech.com/`

platform which integrates a set of extensible feature extraction methods with a visualization engine within an interactive environment. It seeks four goals: (1) provide a platform for integrating and visualizing movement and its characteristics from a variety of data sources or representations (for example, video recordings, motion capture, accelerometer, and physiological be visualized together); (2) provide an analytical tool for researchers interested in analyzing movement characteristics of a human actor; (3) provide a research tool that can facilitate development and evaluation of movement feature extraction techniques; (4) be used for analyzing both the recorded movements of real humans and artificially generated movements of virtual characters.

The main contributions of this paper are as follows:

- It is a general purpose movement visualization and analysis platform which supports discrete and continuous features.
- It uses the parallel visual processing capabilities of human perception to visualize multiple features of the movement in parallel and in different forms which can be used to better understand the relationships between a particular class of movements and their corresponding measurable features.
- Mova is open-source and web-based which makes it suitable to be used in many applications including a front-end for movement databases where users can preview/examine the contents of each database entry.
- It is extensible: one can add new visualization techniques or feature extraction methods to the platform.

The prototype of Mova is accessible using the supplemented website mentioned in the abstract.

2. BACKGROUND AND RELATED WORK

2.1 Visualizing Human Movement

Different techniques can be used to visualize movement and its characteristics. The raw movement data can be simply visualized using the video recording of the performer or through animating the skeletal information. There are notational systems such as the Benesh, Eshkol-Wachman, and Labanotation that are used in order to describe choreographies. For other movement characteristics, visualization techniques are rather arbitrary.

Works on human movement visualization can be divided in three groups in terms of their applications: (1) artistic visualizations, (2) movement summarizations, and (3) movement information analytics.

Artistic visualizations map the movement to aesthetic visual representations. They often target ordinary users rather than researchers and movement analysts and produce more abstract visualizations rather than analytical ones. For example, Bodycloud [Perret, 2009] creates sculptures from the resulting spaces of the movements of an actor. EMVIZ (flow) [Subyen et al., 2013] maps effort qualities to visual representation. through swarming boids.

Movement summarization visualizations are used to provide a synopsis or compare the contents of movement clips, often in a 2D space by projecting or eliminating the time dimension. For example, summarizing the contents of a large movement databases allows its users to easily browse the contents. Furthermore, visualization techniques are also used in order to compare the similarities of a group of movement clips. 2D visualization of movement clips are especially useful as they can be used in 2D media as well. Motion Belts [Yasuda et al., 2008] creates a timeline of 2D postures of key-frames of a clip. In this technique, the orientation of each body part is represented by a circular color scale. Motion Track [Hu et al., 2010] shows the variations within movement clips by first creating a 2D reference space of all key-frames within a database and then drawing a track for each given movement clip. As a result, similar movements would have tracks in the same areas of the space. Similarly, Motion Map [Sakamoto et al., 2004] depicts the trajectory of a movement in a reference space along with some key-poses across the space. Action Synopsis [Assa et al., 2005] technique illustrates short movements in still images by selected a set of representative key-poses that summarize the whole movement.

Movement information analytics provide further insights about the characteristics of the movement which are used in order to evaluate and understand a particular movement or a class of movements. Such visualizations are used by researchers, movement analysts, or choreographers in order to draw conclusions about the actor of the movement or the type of the movement he or she is performing. For example, ActionPlot [Carlson et al., 2011] is a visualization tool for contemporary dance that provides structural analysis of dance performances though codifying the movements and providing more information about the performance. It visualizes the meanings, structural information, the performer's attention or intention, the effort, the tempo of the effort, the balance of the movement, and the timing of actions being performed. Synchronous Objects [Palazzi and Shaw, 2013] uses visualization in order to provide choreographic structures of a performance. It is intended to provide a graphical language that can be used by researchers in an interdisciplinary environment to examine the relationships between the space, structure, and movement.

2.2 Movement Feature Extraction

Movement features can be derived from any type of sensor systems that can record human movement such video, motion capture, and accelerometers.

Features are extracted in three ways: (1) using manual annotations determined by a human expert, (2) using algorithmic methods, and (3) using machine learning techniques.

Volpe [2003] suggest a set of motion descriptors and expressive cues such as Quantity of Motion (QoM), Contraction Index, Motion Strokes, Fluency, and Impulsiveness that are used in interactive multimedia systems for performing arts. Mentis and Johansson [2013] propose a set of rules to recognize Laban Movement Analysis (LMA) Effort parameters of the wrist joint. Kapadia et al. [2013] also propose a set of formulas to calculate Body, Effort, and Shape properties of a movement based on LMA. Such features are used to index a movement database which allows the user of the database to query movement clips using a set of desired feature values. EyesWeb [Camurri et al., 1999] extracts general space and gesture features from real-time video data. These features are used to determine the affects and emotions of the actors and are used to control sound, music, visual media, as well as to control actuators such as robots.

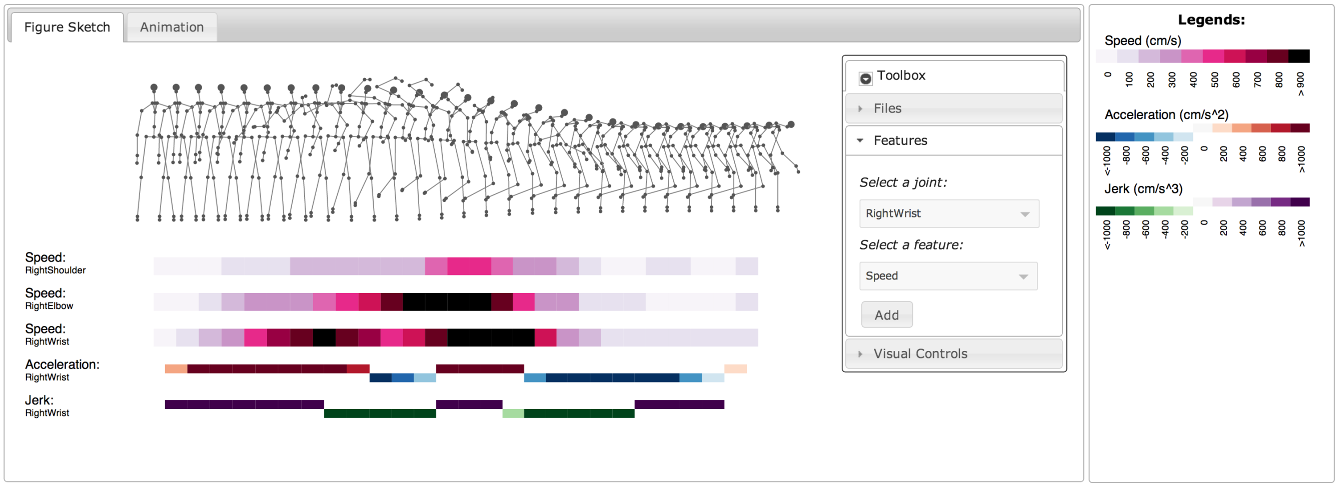


Figure 1: The main window of Mova visualizing kinematic features of a punch

Machine learning is used for detecting features of movement instead of explicitly defining rules or algorithms. Gesture Follower [Bevilacqua et al., 2007] uses Hidden Markov Models to recognize gestures which is (among other possible applications) mainly used for music pedagogy. Zhao and Badler [2005] use neural networks in order to extract Laban Effort qualities of live performances from both 3D motion capture and 2D video data. EffortDetect [Maranan et al., 2014] is a wearable system for real-time recognition of Laban Effort qualities using artificial neural networks.

Our work is a general purpose platform which can be integrated with multiple feature extraction methods that were proposed in the literature in order to provide visualizations of such features for analytical purposes.

3. MOVEMENT DATA

While designed to support multi-modal movement data in different representations, the current prototype of Mova only uses motion capture (mocap) data. In future, other data representations will also be added to the system. Mocap is a well known approach for recording movement and is highly used in industry. Mocap systems use marker or markerless techniques to capture the position and orientation of body joints in a 3D coordinate system. These positions are mapped into a virtual skeleton and are often converted into a hierarchy of joint angle rotations to ensure the fixed limbs length.

Mova uses 3D position of the body joints for calculating the features and visualizing the skeleton. Mocap files in different formats (Biovision BVH, Acclaim, Collada, etc) are converted to an internal format in order to be used in Mova. The internal format which is used by Mova consists of the skeletal structure of the body and the position of each joint for every frame.

Mocap data are recorded with rates as high as 160 frames-per-second. However, in order to make the feature extractions computationally tractable, only a subset of frames is selected for manipulation. This selection can be done in two ways: (1) by linearly sampling every k-th frame or (2) by extracting *key-frames*.

With the former approach the user can specify the number of frames to skip which also defines the level of granularity of the features. The latter approach extracts a set of frames within the movement that, while sparse in time, are representative for the contents of the movement. The current prototype of the Mova uses the first approach. A future extension of Mova will include key-frame extraction capability.

4. SYSTEM DESIGN

Mova consists of three components: feature extraction components, visualization engine, and the graphical user interface (GUI).

The feature extraction component consists of a library of feature extraction methods. Each method analyzes the input movement data and returns the extracted values representing a feature for a specific body part or a group of body parts during the course of the movement as defined by the user. The features library also includes the information about the type of each feature (see Section 5) and the scale of the output values.

The visualization engine provides visual representations of the input movement clip and its extracted features. It particularly takes a parallel approach in visualizing the movement with multiple features: first, it provides multiple visualization techniques for the same feature and second it visualizes multiple features in the same screen. This allows the user to better observe the relationship of the features with one another and with the postures in the movement.

The GUI allows the user to load movement data, select the features and the joints to be visualized, choose between different types of visualizations, and control the properties of the system. The GUI also supports user interactions with the visualizations which enhances the efficiency and usability of the system.

5. FEATURE EXTRACTION

Features are extracted from the changes of the body joints from one posture (frame) to another. These changes are determined from the position or rotation of body joints which are provided in the raw input mocap data. It is also possible to calculate features based on other features. For example, kinematics can be calculated directly from joint positions. Effort qualities are be derived from these kinematics features

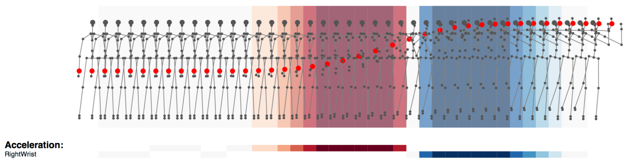


Figure 2: Figure Sketch for a sample movement with the values of acceleration of the right wrist projected on it.

and the emotions of the actor can be further determined based on the effort qualities of movement. Mova calculates features from the movement data based the definitions described below:

Definition 1. P_k^j represents the 3D position of the joint j at frame k.

Definition 2. R_k^j represents the rotation of the joint j at frame k.

Definition 3. Each frame (m_k) contains a set of positions (or rotations) for each joint defined in the virtual skeleton in the input data: $m_k = \{P_k^1, P_k^2, ..., P_k^G,\}$ where G is the total number of joints.

Definition 4. A movement clip is a set of consecutive frames with the length of N: $MOV = \big\{m_n | \forall n \in \{1, 2, .., N\}\big\}$.

Definition 5. In order to calculate movement features, a smaller subset of frames are selected from the original movement clip. The length of the selected frames set is much smaller than the length of the original movement clip: $SF = \big\{m_k | \forall k \in \{1, 2, .., K\}\big\}, K << N, SF \subset MOV$.

Definition 6. A movement feature describes a characteristic of the movement that is measured from the changes between two postures. The movement clip is then described by a set of feature values $\{f_1, f_2, ..., f_l\}$ which is calculated from the function g of the selected frames:

$$g : SF \rightarrow \{f_1, f_2, ..., f_l\}$$

Definition 7. Each feature value, f_i, is defined by:

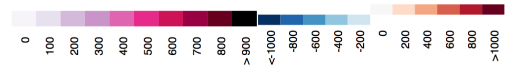
$$f_i = \big([start_i, end_i), value_i\big)$$

The $start_i$ and end_i together represent the frame indices that define the window within the movement clip which the value is associated with.

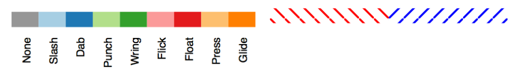
Definition 8. Based on the type the feature, the *value* can take three different forms:

$$value = \begin{cases} r \in \mathbb{R} & (1) \\ s \in \{s_1, s_2, ..., s_n\}, & (2) \\ \emptyset & (3) \end{cases}$$

(1) represents continuous real valued features such as speed or acceleration. (2) represents a finite set of discrete properties such as annotations. (3) represents features that only divide the movement into segments and thus only the start and end values of each segment are considered.



(a) Sequential Range (b) Diverging Sequential Range



(c) Annotations (d) Segments

Figure 3: Visualizing different types of features

Example Features

Below, is a list of movement characteristics that can be extracted and visualized in Mova using continuous, discrete, or segmented features. These features can be examined in terms of their functional, executional, or expressive qualities. Different approaches have been proposed in the literature in order to determine each feature and can be implemented in Mova (e.g., [Volpe, 2003, Kapadia et al., 2013, Mentis and Johansson, 2013, Maranan et al., 2014]).

- Kinematics: speed, acceleration, jerk.
- Laban effort parameters: space, time, weight, and flow
- Body shape measures (e.g., contraction/expansion of body)
- Gestures (e.g., swipe, drawing shapes, etc)
- Emotions (detecting emotions from posture and dynamic qualities of movement)
- Health conditions and gait patterns

  In order to test and demonstrate Mova, kinematics and Laban effort parameters are implemented in the prototype while the rest can be plugged-in to the system.

6. MOVEMENT VISUALIZATION

This section presents the design decisions and the techniques that are used in Mova for visualizing the movement and its features. The main window of the platform includes the tabs for accessing the Figure Sketch and the Animation visualizations, the features timeline, the legends, and the toolbox (Figure 1). We briefly describe each of these parts below.

Figure Sketch

Figure Sketch gives a general overview of the contents of the movement and its flow in a timeline in a 2D space (Figure 2). The visualization is done by drawing the postures from consecutive selected frames (from the SF set) within a short distance (controlled by a padding parameter) next to each other. The Figure Sketch can also be changed based on user interactions with other parts of the visualization.

Features Timeline

The features timeline represents the list of the features that are extracted from the movement. Each feature corresponds to a chosen joint by the user and is visualized as a timeline aligned with the postures on the Figure Sketech. This alignment allows the user to match each posture with the feature

Figure 4: Drawing the trajectory of the right wrist joint colored based on the value of its speed while playing the animation.

values that are calculated from the same time frame in the movement.

Depending on the type of the feature, a different visualization approach is used to illustrate the values:

- Real, continuous values that vary within a specified range are visualized using a multi-hued scale by varying the lightness of the colors proportionate to the value of the feature and the total range (Figure 3.a).
- Real, continuous values that vary within two diverging ranges centred on a pivot point (thus representing opposite polarities) are visualized using a distinct multi-hued scale for each polarity. The closer the value is to the pivot point, the lighter its color is. In addition, for better distinction of the ranges, the positive range is positioned higher than the baseline and the negative range is positioned below the baseline (Figure 3.b).
- Annotation are illustrated with a different color for each label (Figure 3.c). As annotations represent qualitative aspects of the movement and do not imply any order, the colors used for their visualization have different hues while their brightness are almost the same.
- Unlabelled segments that divide the movement clip into separate parts are visualized by the boundaries of the segments and an alternating fill pattern (Figure 3.d).

To get a better contrast and clarity in representing sequential data, we chose multi-hued color scales over single-hued scales. Multi-hued color scales use two or more hue levels in order to create a lightness gradient which makes it more difficult to design them. In order to automatically create good quality multi-hued scales Bezier interpolation and lightness correction [Aisch, 2013] are used (Figure 5).

In order to provide an easier perception of the relationship between the feature values and the state of the movement that they represent, upon hovering the mouse pointer over a feature timeline, an overlay of the feature values are projected behind the Figure Sketch (Figure 2). In addition, the joint which the feature is extracted from is highlighted.

Animation

The animation tab allows the user to play the movement as an animation. While animation is being played, the feature values that correspond to the current frame of the animation are highlighted.

The trajectory of a joint can be also drawn during the animation. The trajectory is visualized based on the value of a selected feature for that particular joint (Figure 4).

Figure 5: a) single hue vs b) multi-hued vs c) multi-hued with Bezier interpolation and lightness correction.

GUI Controls

Mova is an interactive platform which allows the user to manipulate the properties of the system though a toolbox. The toolbox includes controls for opening input files, selecting the joints and their features to be visualized, and changing the properties of the visualizations.

The file handling tool allows the user to upload new files or choose a previously uploaded file from the list to be visualized/analyzed. In addition, the user can save a snapshot of the current visualization in the form of a PDF or SVG graphic.

The feature selection tool allows the user to add new features to the features timeline by choosing a joint and a feature. Selecting the joint is made easy by displaying the skeleton to the user so that the user can click on the desired joint. Once added, the selected feature will be calculated for the specified joint and will be added to the timeline. The user can remove any of the features from the timeline once the feature is no longer needed.

The visual controls tool allows the user to change the visual properties of the system. The user can change the number of frames to sample for calculations (which is related to creating the *Selected Frames (SF)* set) which provides a form of *zooming* in terms of the granularity of the data being processed. It also allows the user to change the padding between each figure in the Figure Sketch which provides another form of *zooming* in terms of spacing the visualization at the pixel level.

7. IMPLEMENTATION

Mova is open-source and implemented from scratch as a web-based application in Javascript using open-source libraries. Its graphical user interface is built using *jQuery* library [The jQuery Foundation, 2013] and visualizations are implemented using *D3.js* library [Bostock, 2013]. All the visualizations are implemented as Scalable Vector Graphics (SVG).

The features can be implemented in Javascript on the client-side or they can be hosted on a remote and more powerful machine and be called upon the need.

The complete source-code of the tool is available at `https://github.com/omimo/Mova`.

8. TEST CASES

In this section we present three scenarios in which Mova can be used:

In the first scenario, a researcher implements a number of feature extraction methods for the same movement feature (for example, the Laban effort space quality) in order to compare and validate them. For doing so, the researcher can import annotated values of the feature that are determined by a certified movement analyst. Using the parallel visualization of each method, the researcher can easily notice which feature extraction methods comply with the expert opinion and thus validate or invalidate them.

In the second scenario Mova can be used in choreography/dance pedagogy or in heath movement analysis: a movement analyst extracts the features of a recorded movement clip from a dancer or a patient and analyzes the qualities of the movement in order to draw conclusions about the the performance of the dancer or the health conditions of the patient. In a similar way, one can evaluate the naturalness of the movements of a virtual character that are generated artificially by computer programs.

In the third scenario, Mova is used as a front-end of a movement database. Users can browse the contents of the database and open an entry of movement data (that is possibly recorded using multiple sensors) in order to examine its contents or evaluate its characteristics.

9. CONCLUSION AND FUTURE WORK

We have introduced a prototype of an interactive platform for movement analytics which allows human movement experts and ordinary users to examine movement data in order to determine the underlying information and the characteristics they convey. The platform is interactive and allows its user to manipulate the visualizations. An important aspect of the platform is its use of the parallel visual processing capabilities of human perception in illustrating multiple features of the movement aligned with its postural representation.

Further developments of this prototype system include implementing:

- the support for combining multi-modal movement data such as video, mocap, accelerometers, breath sensors, and physiological sensors;
- a rich library of movement feature extraction methods proposed in the literature;
- automatic key-frame extraction;
- the support for features that involve a group of joints;
- the support for comparing the features of two or more movement clips;
- the support for inserting annotations to a movement clip;
- more variations of visualization techniques.

Acknowledgements

This work is supported by NSERC, SSHRC, and Canarie.

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