Technical Article (2016), pp. 1–4
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Manipulating Motion Signals to Emphasis Stylistic (Life-Like) Qualities

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Abstract

This paper presents a method for manipulating internal animated motion signals to help emphasis stylistic qualities while upholding essential control mechanistics. The adaptation and filtering of articulated joint signals is challenging due to the highly coupled and hierarchical nature of the problem. We map articulated skeletons onto inanimate objects and explore animated control limitations while transferring stylistic qualities from pre-recorded solutions (e.g., motion capture). What is more, we transform joint signals from the spatial to frequency domains using a Fourier transform to break the problem down into a combination of simpler elements. We use this to filter specific features in such a way to add or subtract stylistic qualities (tired, happy, worried). We also modulate the signal components with their derivatives to inject motion characteristics, like stretch, squash, anticipation and follow-through. The modified joints signal are applied to the projected null-space of the Jacobian to ensure the final motions obey the original control requirements (e.g., foot support transitions). The method is straightforward and can be accomplished automatically without much user intervention. The user only needs to specify the required filter parameters. We demonstrate the advantages of our approach by modifying a variety of complex motion sequences (acrobatics, dancing, and walking actions) to add or remove stylistic qualities.

Keywords: inanimate, signals, animation, character, filter, Fourier transform, frequency, null-space, kinematics, control, motion

1 Introduction

Inanimate Objects We are surrounded by inanimate objects. Objects that do not breath, change or live. Examples include tables, lamps, pencils, buildings, windows, books and even computers. Inanimate objects are dull 'lifeless' and spiritless. However, in this paper, we superimpose (inject) personality through poses and movements into objects, such as, lamps and books. We discuss extracting features and styles from organic creatures (underlying rhythmic signals). The signals that form the 'soul' of the motion are possessed by these otherwise static passive objects. This is possible through the 'power of motion', imagination and creativity (see Figure 3). Animators spend years learning and practising skills to digitally animate objects in a life-like manner (extremely costly and time-consuming).

Animation The 'animation' of objects (inanimate or otherwise) is relatively common and straightforward (e.g., skinning, deformation and skeletal techniques) [FOKGM07]. For instance, a human body organ oscillates in a rhythmic pattern based on the body's need (heart or lungs), but is very limited in its capabilities or response repertoire. Yet it is alive (since it moves and is composed of living biological tissue). Similarly, a toy car controlled via remote and motors possesses sensors to allow it to navigate complex environments. Hence, we need to be careful what we mean by 'animated'. To be able to adapt and have a perceived self-need or purpose in addition to a self-agency with a physical-presence. Acting on forces (both internally and externally) to interact and drive a physical structure.

Classifying Style & Behaviour Based on the movement of a creature, how do we classify the stylistic personality or the behavioural model? Humans and even simple animals possess a rich set of motions that are characterised in many aspects that relate to different: behaviours, styles, or activities. For example, simple repetitive or ritualistic movements (or even posture), such as, the body rocking or as complex as crossing and uncrossing of legs, and marching in place enables the identification of behaviours and stereotypies [MJ09, Ski90]. We take an experimental view of behavioural and stylistic qualities in this paper. Concentrating on a few common examples that are easy to identify and class (e.g., tired, scared, happy, energetic). What is more, we map these styles of intelligent humanistic behaviour onto inanimate objects to obtain transference of personification [VSS02]. For example, two identical motions may achieve the same task, but one might appear sad or tired due to the sluggish low-energy movements (i.e., damping the signals so the actions drag the body along through forces, contacts and constraints). In the same way, overemphasising or exaggerating underlying motions, has the ability to inject a whole new stylistic qualities. An entertaining example of this is shown by Monty Python in the Ministry of Silly Walks [Pyt70] taking walking to the extremes.

Animated Motions Pre-recorded animations are a popular technique for reproducing highly detailed and believable movements. These animations are able to be adapted and re-targeted to specific situations, such as, changing environments and character topologies. One noteworthy approach is through kinematic techniques, in particular inverse kinematics, for instance, the Jacobian and projected null-space [CK99, Lie77]. Although the redundant null-space of an articulated systems has been deeply studied in the kinematic domain (especially in the context of robotics, such as, primary and secondary tasks, singularities and collision avoidance), this is not the case in motion filtering [Chi97, BT92, Ken12]. In our research, we identify kinematic redundancies and exploit them to create an effective and efficient solution for controlling compliant filtered behaviours (i.e., modifying the 'internal' motions within the null-space and associated end-effector task space).

Signals An articulated animation is essentially a collection of joint signals. Hence, it should come as no surprise that techniques can be used to emphasise or remove particular 'components' of an animation via signal processing methods. For example, Wang et al [WDAC06] mixed the joint signals with the second derivative of the original signal to create more 'alive' animations, while Unuma et al. [UAT95] transformed the joint signals to the frequency domain using a Fourier transform to identify and modify emotional elements of a character's movement. However, there are a number of challenges when adapting or modifying pre-recorded animations, such as, the modified animation must still possess the underpinning life-like properties and remain physically correct (joint limits); the original motion requirements must be enforced, such as, end-effectors (feet on the ground or hands at specific locations); and finally, the new joint signals must be coherent and organic (i.e., avoid snapping or jerky transitions).

Coupled Articulated joint signals are 'not' independent of one another. An animated structure's limbs are connected in a hierarchical configuration (Figure 5). Hence, modifications to limbs lower in the hierarchy will cause large ramifications to the overall motion. This is one of the key challenges we address in this paper. Our solution uses the joint signals to represent the internal style, while the end-effectors provide coordinated control constraints. The kinematic redundancy in conjunction with the Jacobian matrix null-space to control the filtered joint signals (ensuring compliant behaviour of the end-effector trajectories). The Fourier transform enables us to 'partition' up the signals, so we are able to apply filtering techniques to selective regions (e.g., emotional characteristics [UAT95]). Our method is straightforward to implement and provides a best guess solution for unobtainable goals (for instance, when filtering causes extreme joint signals).

Contribution The key contributions of this paper are: (1) coordinated inanimate object stylistic signal mapping (organic to inorganic objects) - while an artist is able to 'manually' rig objects and animate them (we offer methods to filter and control these motions); (2) the application of the Jacobian null-space with filters in the frequency domain; and (3) the Fourier transform to split the joint signals into multiple components to help classify and target specific motion types (e.g., breathing).

2 Related Work

Motion Signal Processing Unuma et al. [UAT95] was one of the first to use motion signal techniques to interpolate and extrapolate animation sequences (e.g. brisk, tired, fast, ...) in the frequency domain. This was followed by the work by Amaya et al. [ABC96] who used the frequency Fourier analysis to generate emotional animation from neutral human motion. The approach did not address squash and stretch effects - however, a method for addressing this limitation was introduced by Wang et al. [WDAC06], by feeding back the second derivative of the signal. Effects of speeding up or slowing down specific motion elements and their effects on our perception [CL13]. Similar work by Liu et al. [LTF*05] presented a method for motion magnification to extract small motions and multiply the magnitudes of the motion by a constant for re-rendering an exaggerated. Initial work on motion signal processing treated the key-frame parameters as sampled signals [BW95], and did not address the coupled nature of the joint signals. What is more, the decouple motion editing did not discuss or integrate any constraint satisfaction techniques. Nevertheless, these waveshaping techniques [BW95, Gle98], form the basis of animation signal processing techniques and demonstrated the enormous potential of customizing and shaping animated pre-recorded motions. Enabling the modification to embed emotional and stylistic qualities (exaggeration) while preserving the distinctive 'signature' of the captured motion [BW95].

Kinematic Constraints Previously the enforcement of kinematic constraints has largely been a separate process that depended upon expensive optimization procedures [WDAC06, BB04]. Our approach on the other hand, presents an efficient solution that works in cooperation with the signal processing algorithm to create a stable system - even in near-singular configurations. The speed and reliability of our algorithm makes it uniquely suited for automated contexts, allowing motions to be modified or enhanced without user intervention.

Our Work Our work combines a number of techniques: the filtering of emotional components using a Fourier transform as shown by Unuma et al. [UAT95, Ken15], mixing the second derivative of the signal to add a wide variety of motions, such as, anticipation, follow-through, and stretch [WDAC06], speeding-up and slowing down regions of the motion (perception of animacy) [CL13], and the weighting of the pseudo-inverse kinematic constraints with priority conditioning [Ken12].

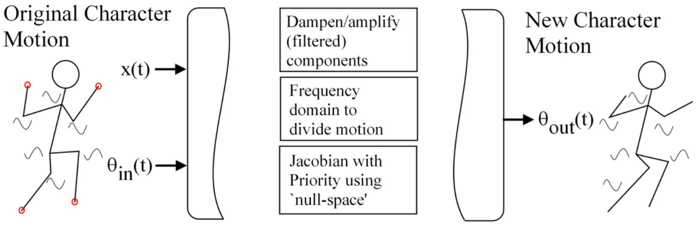

Figure 1: **Overview** - Adapting motion capture data to amplify or dampen specific stylistic components, while enforcing particular constraints, such as, foot placement locations, to ensure the final motion still possesses the original action's purpose.

3 Method

Jacobian An articulated figure is represented by an array of joint orientations. The end-effectors (feet and hands) can be related to the joint configuration: kinematic mapping $f : \theta \to x$. This maps the joint space θ to the Cartesian space x, as given below by Equation 1:

$$x = f(\theta) \tag{1}$$

where x and θ are arrays. If we differentiate Equation 1, we get the relationship between the rate of change of the end-effectors and joint angles (Equation 2):

$$\dot{x} = J\dot{\theta} \tag{2}$$

where $\dot{x}$ is the end-effector velocity, $\dot{\theta}$ is the joint velocity, and J is the Jacobian. The Jacobian is a matrix that represents the linear relationship between end-effector velocities and joint angle velocities.

Redundancy Inverting the Jacobian allows us to calculate the joint angle velocities from end-effector velocities. However, due to the end-effector having less degrees-of-freedom than the joint angles, the kinematic solution has redundancies, which means the Jacobian inverse is 'not' unique. Hence, we find that there are an infinite number of possible solutions for satisfying Equation 2. We are able solve this by adding additional criteria to create a 'best' fit solution, such as, the minimal norm solution [CK99]. We implement this using a pseudo inverse, as shown in Equation 3 below:

$$\dot{\theta} = J^{+}\dot{x} \tag{3}$$

where $J^{+} = J^{T}(JJ^{T})^{-1}$ and is known as the pseudo inverse of J.

Null-Space The pseudo-inverse has an essential property that we use to add additional control. We expand Equation 3 to use the redundant degrees of freedom. We utilize the redundant degrees of freedom to perform secondary tasks (i.e., the filtered motion space), as shown below in Equation 4:

$$\dot{\theta} = J^{+}\dot{x} + (I - J^{+}J)z \tag{4}$$

where z is an arbitrary array, $(I - J^{+}J)$ projects z onto the null-space of J. The null-space corresponds to the redundant degrees of freedom and was first exploited Liegeois [Lie77]. We optimization in the **null-space of the Jacobian** using a kinematic cost function. This has the benefit of being computationally fast, while the explicit optimization provides control criteria, such as, the arm and foot locations. The pseudo-inverse has an essential property that we use to add additional priority control (i.e., filtering and motion adaptation is done in the null space).

Singularities In practice, we use the damped least square solution [BK05] for Equation 4, i.e., $\dot{\theta} = J^{+}\dot{x} + (\lambda^2 I - J^{+}J)z$. The damped least square solution adds a bias λ that helps deal with numerical singularities and produce a more stable and consistent motion.

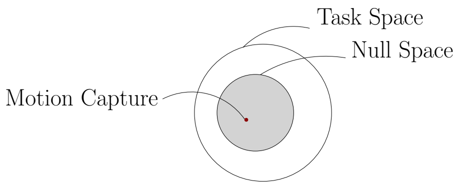

Figure 2: **Null-Space** - Graphical visualization of the null-space.

Primary & Secondary Motion Typically, motion capture data stores the joint angle configurations. We also extract and use the end-effector trajectories. Setting the following:

$$\begin{aligned} \text{original motion: primary } x_1 = f_1(\theta), \quad &\rightarrow \quad \dot{x}_1 = J_1 \dot{\theta} \\ \text{filtered motion: secondary } x_2 = f_2(\theta), \quad &\rightarrow \quad \dot{x}_2 = J_2 \dot{\theta} \end{aligned} \tag{5}$$

Substituting into Equation 6 below:

$$\dot{\theta} = J_1^+ \dot{x}_1 + (I - J_1^+ J_1) J_2^+ \dot{x}_2 \tag{6}$$

where the primary task is always enforced, while the secondary case is optimally achieved, if possible, or best guess approximated. The original motion coordinates the character's movement and contains important information regarding the end-effector trajectories (i.e., the primary task). The secondary task uses the filtered joint signals ($\theta_{filtered}$). For this case, we modify Equation 6 to:

$$\dot{\theta} = J_1^+ \dot{x}_1 + (I - J_1^+ J_1) \dot{\theta}_{filtered} \tag{7}$$

Filtering in the Spatial Domain As presented by Wang et al. [WDAC06], we are able to modify pre-recorded animation to incorporate a wide variety of characteristics, such as, squash, stretch, anticipation and follow-through. This mathematically filter is given using Equation 8 below:

$$\theta^*(t) = \theta(t) - \ddot{\theta}(t) \tag{8}$$

where $\theta^*(t)$ is the filtered output, $\theta(t)$ is the input signal to be filtered, and $\ddot{\theta}(t)$ is the second derivative with respect to time of $\theta(t)$.

Filtering in the Frequency Domain (Fourier Transform) The Fourier transform is a fundamental mathematical notion that allows a signals to be broken down into its component parts. In fact, the Fourier transform is probably one of the most important tools for analysing signals in the field of signal processing [Ken15]. Since a character joint signals are essentially waveforms (function of time). The Fourier transform enables us to decomposes the function of time (joint signals) into separate frequency components. We then apply fundamental operations to these individual frequency components. After applying these operations, we use the inverse Fourier transform to reconstruct the new joints signals. Since Fourier transform focuses on repetitive (rhythmic) signals, we transform local sections of the motion signal to determine the frequency and phase content (i.e., short-time Fourier transform). Furthermore, we use the 'discrete' Fourier transform (DFT). DFT is the 'sampled' Fourier transform and therefore does not contain all frequencies forming an animation signal, but only a set of samples which is detailed enough to describe the spatial domain motion.

For different character actions, we often find that there are a small number of frequencies that dominate the spectrum. Analysing these motion signals enables us to identify these frequencies and corresponding characteristics . Modifying particular signals in select frequency ranges enables us to alter behavioural attributes - which correlates with the work by Unuma [UAT95] and Amaya [ABC96]. We use this to filter a variety of unique and dissimilar actions (e.g., dancing and walking) to influence behavioural attributes.

Hierarchical Ordering An often overlooked characteristics of 'animation' filtering - is that articulated characters are stored in a hierarchy formation. This means, small changes to joint signals at the root cause larger changes at the end-effectors. What is more, the 'root' of pre-recorded animation data is often the hip or pelvis. This means we propagate out changes from the body centre (i.e., two inverse kinematic problems), while in reality, the foot or hand end-effector would be locked and the changes should propagate outwards from there. Of course, the challenge of identifying which foot or hand is locked and re-ordering the hierarchy is difficult and depends on the specific motion. For our adapted animations, we leave the root as the default, i.e., the pelvis, and propagate outwards.

Figure 3: **Inanimate Objects** - Common practice from an early age and culture to embrace inanimate objects to have personality and humanistic life-like qualities

Warm Start Approximation We used a simple iterative technique (i.e., Projected Gauss Seidel) to solve the linear system of equations. This allows us to inject a starting approximation into the solution (i.e., desired joint angles) - upon which the iterative algorithm 'pulled' the solution into alignment with the constraint conditions. While iterative algorithm is essentially serial, it allows us to find a reasonable approximation to the problem with few iterations. Note - a wide variety of algorithms are available for solving the set of linear kinematic equations [ND88], each with their pros and cons.

4 Experimental Results

Our method was applied to a variety of animations (see Figure 4). These animations provided both end-effector trajectory constraints (e.g., see Figure 6) and internal joint signals. The end-effectors provided overall semantic constraints, while the internal signals could be adapted through filtering. Experimental results demonstrated our approaches ability to modify internal joint signals without worrying about the final motion violating the semantic constraints (e.g., when walking, the feet still touch the ground at specified locations during foot support transitions - see Figure 6), while the internal 'behavioural' characteristics can be modified using filters. To maintain semantic constraints, we specify both the feet, hands, or head to ensure they retain their original paths. Adding or removing additional constraints depending upon the action and the desired overall affect (Figure 7). For example, in some situations, we might want to allow the arms to deviate radically from their pre-recorded trajectory to emphasis a more exaggerated motion. While our approach lets us apply simple filtering techniques (e.g., Fourier transform), re-injecting the joint signals secondary derivatives (optionally offset), allows us to do more than remove or add characteristics, but also incorporate interesting features, such as, squash and stretch during abrupt changes (e.g., jumping or landing actions).

5 Discussion

This paper focused on a kinematic problem in the context of filtering while obeying end-effector constraint conditions, and did not address physical attributes, such as, muscle strength and plausibility. Our technique could be expanded to train physically driven models, with additional constraints, for instance, the centre-of-mass trajectory, as shown by Kenwright [Ken12]. Furthermore, since we are dealing with joint signals, a quaternion Fourier transform (QFT) filter is able to be used

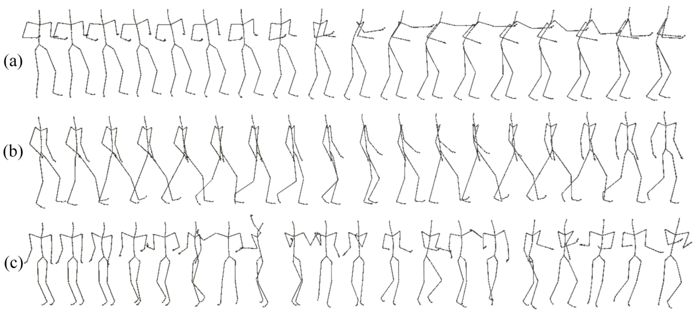

Figure 4: **Test Animations** - (a) standing and punching; (b) walking, and (c) dancing.

(a) (b) (c)

Figure 5: **Skeleton** - Articulated rigid body skeleton - positional end-effector constraints are attached to the (heal and wrist); (a) enforcing end-effector positions (e.g., foot locations) while modifying inner joint angles through filtering, (b) skeleton structure, and (c) adapted and original motions with end-effectors.

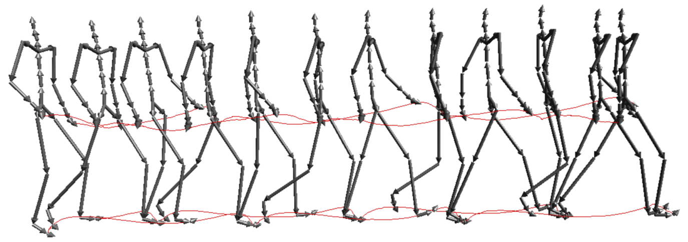

Figure 6: **Walking** - End-effector trajectories from the original motion (hands and feet) to constrain the modified (filtered) motion.

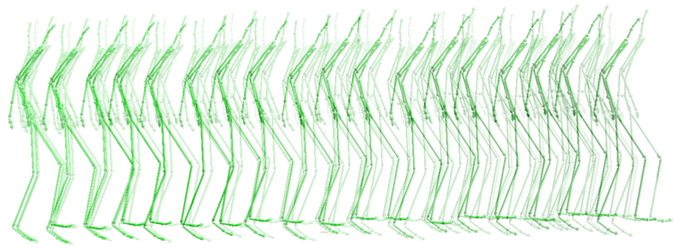

Figure 7: **Walking Posture** - Removal of higher frequency components produces a droopier posture (i.e., tired or sadder).

[Ken15], which operates on joint signals in a holistic manner (i.e., unifying the three angular degrees of freedom). Our approach demonstrated the concept for a single level priority scheme (i.e., end effectors and joint angles), however, this could be extended to multiple priority ordering, allowing the user to mix in a variety of filtered signals with different precedence [BB04].

6 Conclusion

In conclusion, we have shown that kinematic redundancy in conjunction with the Jacobian matrix null-space offers an effective method for controlling filtered joint signals (ensuring compliant behaviour of the end-effector trajectory). Our method is straightforward to implement and provides a best guess solution for difficult situation (e.g., when filter parameters are out of range and produce erratic joint signals). Certain limitations are inherent with our implementation. We solve the kinematic equations using an uncomplicated projected Gauss-Seidel algorithm, which is a gradient based technique, but has problems solutions with limits (i.e., joint angular constraints). However, in the majority of cases the original and filtered signals possess high coherency to produced accepted results.

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