FingerWalk: Controlling Human Gait Animation using Finger Walk on a Multi-touch Surface

ABSTRACT

This paper proposes analyzing finger touches on a conventional tablet computer to support locomotion control of virtual characters. Although human finger movements and leg movements are not fully equivalent kinematically and dynamically, we can successfully extract intended gait parameters from finger touches to drive virtual avatars to locomote in different styles. User studies with 4 participants show that their finger pattern walk for different gaits such as variants of walking (normal, fast, tip-toe) and running do not show significant variations in temporal profiles. This suggests that the finger walk gestures on multi-touch tablets may have the potential for more universal adoption as a convenient means for end users to control gait nuances of their avatar as they navigate in virtual worlds and interact with other avatars.

Author Keywords

Touch input, character animation, walking animation.

ACM Classification Keywords

H.5.2 User Interfaces : Input devices & strategies; I.3.7 Three Dimensional Graphics and Realism : Animation.

INTRODUCTION

How to animate virtual characters easily and intuitively has been a long-term problem of interest in the Computer Animation community. Manipulating many coordinated Degrees of Freedom (DoFs) in both space and time is extremely challenging, even for professional animators. Over the years, different types of animation interfaces have been proposed, such as performance-driven interfaces [4], speech-based interfaces [23], sketch-based interfaces [19], and touch-based interfaces [11].

Different types of interface manifest different strengths and weaknesses in different application scenarios for animating different motion tasks. In this paper, we focus on animating avatar locomotion, the most common motor task seen in virtual reality applications and computer games. We explore the iPad2 multi-touch interface to map finger touches first to parameterized locomotory gaits and then to full-body animations.

Multi-touch input is becoming a highly ubiquitous technology, widely used by the general public as can be seen in many commercial hardware products available in the market. Perhaps due to the fact that we are too familiar with mouse controls in desktop computing environments, for nearly all multi-touch applications and interfaces, they simply employ only the center position of finger touch blobs, and apply a finger touch as if it works like a mouse cursor.

However, as pointed out by Cao et al. [2] and Holz and Baudisch [8], a finger touch can carry much more information than merely a single 2D point, by looking at the detected contact shape on the multi-touch surface, we in fact can determine the orientation and pose of fingers relative the contact surface. By this, we can better understand users' intention on each touch, thereby allowing us to further enhance the use of multi-touch in different application contexts.

Figure 1. Walking with your fingers.

Following the spirit of these pioneering studies, we design and implement a two-finger walking animation system to control character walking animation (see Figure 1). This is a highly intuitive setting, where we can simply tap two of our fingers on a multi-touch surface and simulate human's walking naturally by tipping and moving our fingers. In particular, our goal is to analyze the finger touch information available on the commodity tablet computer and derive novel solutions to infer the finger pose and orientation during the walking simulation. By this, we have the possibility to produce more interesting walking animation effects with body balancing and moon walking,

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which are not possible to achieve if we regard multi-touch contacts as mouse cursor points only.

In detail, our system is implemented and experimented on a widely available tablet computer, the Apple iPad2, and we employed the *x* and *y* locations, as well as blob radius information from the machine to support our finger contact analysis. By analyzing various walking patterns with these parameters over time, we found that it is possible to use the temporal changes of input signals from the multi-touch tablet to control the animation of human gaits such as walking, running, hopping and limping. Nuances in these gaits can also be inferred from the finger pressure applied during the execution of the finger walk gestures. Our user study of 4 participants demonstrates that the signatures acquired for the various finger walk gaits do not change significantly.

RELATED WORK

Since the developing of interaction technologies on multi-touch, there have been a number of research work studying the application of multi-touch to manipulate 2D graphical objects [9, 16] as well as 3D models [5, 7, 10] and camera views [18]. And recently, some researchers began to study the use of multi-touch for animation controls; in particular, multi-touch is useful to allow multiple degrees-of-freedom controls simultaneously with more than one finger. Krause et al. [14] outlined a multi-touch approach to directly manipulate and animate an articulated model. Ceylan and Capin [3] created animations of 3D mesh deformation by applying multi-touch to locally deform pre-segmented 3D object parts. Kipp and Nguyen [11] designed a bimanual multi-touch widget to control and animate the 3D movement of an articulated arm.

It is well-known in Computer Animation that the intrinsic dimensionalityof coordinated human locomotion is low, even though a typical kinematic human skeleton contains around 50 Degrees of Freedom (DoFs). The seminal work of van de Panne [20] first demonstrated that footprint locations and their timings are effective in synthesizing animated locomotion for bipedal figures. Torkos and van de Panne [19] later generalized the footprint-based method to quadruped locomotion synthesis. The specification of footprint locations and timing, however, is not trivial. They can either be specified manually, which is not intuitive and time consuming; or through a global path planner, which is not suited for interactive applications. Many alternative techniques have been proposed over the years to address this challenge. Yin and Pai [22] employed a pressure sensor pad to capture foot pressure distributions in space and time, which can then be mapped to full-body motions to interactively control virtual avatars. Kolhoff et al. [11] proposed using two pens on a tablet to specify footprints. Oshita [15] further mapped the tilt, pressure, speed and position of a pen to control full-body locomotion of a virtual avatar. Yoshizaki et al. [23] utilized a physical puppet which has roughly the same number of DoFs as that of a digital manikin to control its full-body poses. Note that in our work, we only use finger contact information on a multi-touch surface to estimate footprints.

HUMAN GAIT ANALYSIS

Though the focus of this work is to control human gaits such as walking and running, the work starts with the challenge of simulating the human anatomical component that contacts the ground, namely the human left and right feet. This makes sense, since the only information that one can inferred from finger interaction on a multi-touch surface is related the temporal and touch-pressure characteristics of the user's two surface contacting fingers. However, the reality is that posture changes of the feet alone are not sufficient to completely specify the complexity and variety of human gaits. Nonetheless, the way the feet posture changes with time contributes significantly to the determination of what possible human gaits is being performed. The main thrust of this work is to investigate how far one can go in realistically animating a variety of human gaits with hierarchical modeling of finger touch to feet posture to human gait. To begin, we first need to have some fundamental understanding of human gait analysis.

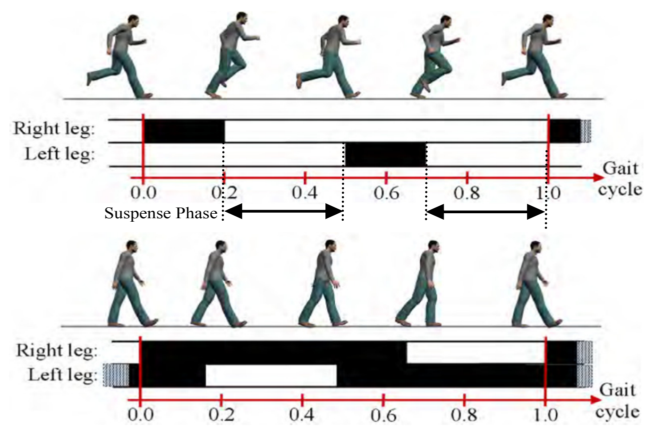
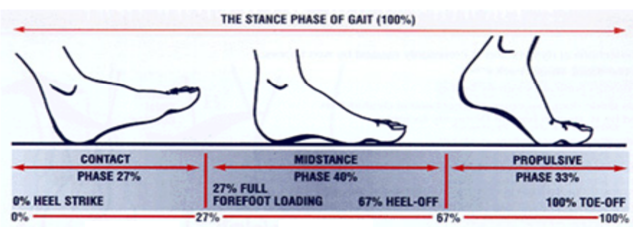


Figure 2. Duty factor of running (top) and walking (bottom). Adapted from [25]. The suspense phase occurs during running when both legs are above the ground.

The typical human gait cycle consist of two phases. The cycle begins with a *stance phase*, where one foot contacts the ground and produces forward propulsion for the foot to lift off the ground to go into the *swing phase*. The foot then contacts the ground again to repeat this cycle. The stance and swing phase accounts for approximately 60% and 40% of a gain cycle, respectively [26]. The duration of the stance phase in relation to the entire gait cycle duration is often called the *duty factor* [25]. As shown in Figure 2, duty factor can be a good measure to differentiate between the running and walking gait. The former is always smaller compared to the latter. Human gait is often viewed as a continuum, for example, one cannot say when jogging begins and running starts [25]. However, running is not done by walking faster. Physiological research has shown that the optimal action changes discontinuously with increasing speed [1]. In this work for example, we demarcate the walking and running gaits when the *suspended phase* is first observed. This is the phase when both feet, or fingers in our case, are off the ground (see Figure 2).

Another variable in human gait is the foot strike, which specifies which part of the foot contacts the ground first. There are three basic foot strikes [27]. The first is the *forefoot strike*, where the foot lands with the ball of the foot first. This is common in the sprinting gait and the heel does not contact the ground at all. The second is the *midfoot strike*, where the foot lands on the heel and ball simultaneously, much like a flat foot landing. The final is the *heel strike*, which is the most typical of the walking gait, where the foot lands on the heel and then pronates to ball of the foot to complete the stance phase with a propulsive stage (see Figure 3).

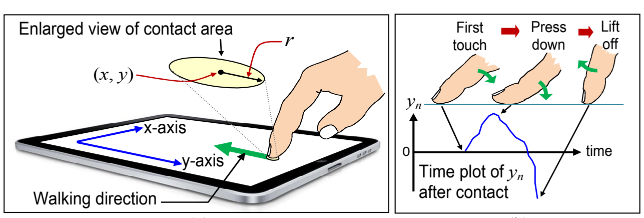


(a) (b) (c)

Figure 3. The stance phase of the human gait cycle [26]. The (a) Contact, (b) Midstance and (c) Propulsive phases.

FINGER WALK ON A MULTI-TOUCH SURFACE

A single finger touch on the interactive surface of a multi-touch tablet (e.g. Apple's iPad) produces 2 basic types of information about the characteristic of the touch. As shown in Figure 4(a), the first is the 2-dimensional centroid coordinates of the contacting ellipsoidal area given by (x, y). The second is the major radius (r) of this contact area.



(a) (b)

Figure 4. (a) Information obtained during finger touch. The centroid coordinates (x,y) and the major radius r. (b) The touch traversal profile (in blue) of localized value y_n when a finger first touches the surface, is pressed down and then released with a finger lift off.

In order to understand how the centroid of the contact area changes during the duration of the finger touch, we can localize the x and y coordinates into (x_n, y_n) by registering the coordinates (x_f, y_f), captured when the finger first touches the surface and then subtracting all subsequent coordinate values with the first-touch coordinate using $(x-x_f, y-y_f)$. Since the finger is walking towards smaller values of y, as shown in Figure 4(a), the localized value y_n is positive if it moves in the direction opposite of the walking direction and negative is it in the same direction.

Touch Traversal Profile

What is intuitive about a soft finger touch is that the harder one presses down on the surface, the larger will be the contacting ellipsoidal area because of the spreading of the deforming finger tip flesh over the contact surface. In short, the major radius r will increase with finger pressure. However, what is less intuitive and was observed during our preliminary experimentation, is the manner in which the y_n value changes as finger pressure is increased because the finger naturally bends during the application of additional pressure, as shown in Figure 4(b). This creates an interesting temporal profile for y_n as the finger presses down and is then lifted up to simulate the landing and lifting of a foot. We call this time plot shown in Figure 4(b) the *touch traversal profile* (TTP). The contact blob centroid is observed to move backward after initial contact and as pressure is applied to the finger. It then starts moving forward as pressure is released and the finger moves towards lift off. In this work, the touch traversal profile is used to model the temporal variation of the stance phase of the foot as is shown in Figure 3, in other words, the heel roll action that occurs during normal walking.

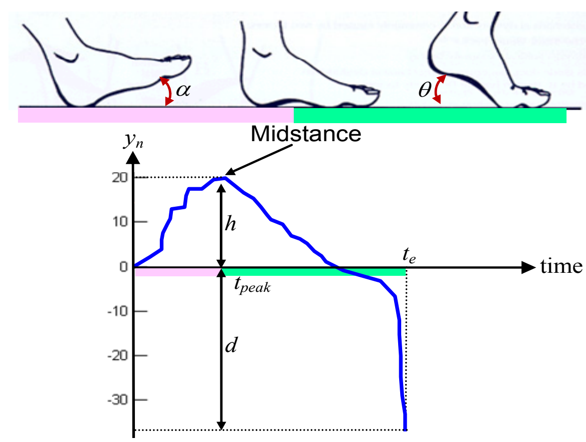


Figure 5. Relationship of the touch traversal profile (in blue) to the stance phase of human gait cycle.

With reference to the TTP parameters given in Figure 5, the angle α with which the heel strikes the ground, is modeled as

$$\alpha = \alpha_{\max} * (h - y_n)/H_{\max} \quad (1)$$

Where $\alpha_{\max}$ is the largest permissible heel strike angle (set to 45° in our experiments) and $H_{\max}$ is a pre-determined upper value of the back travel peak h that was empirically determines to be 20 touch pixel width (from observations in Figure 12(a)). Once the localized value of y_n reaches its peak value at time t_{peak}, the angle α will have reached zero and the foot will be in the midstance position. Further time progression will cause the feet to pronate towards the ball of the foot and increase the angle θ will begin and its growth is modeled as

$$\theta = \theta_{\max} * (h - y_n)/(h + D_{max}) \qquad (2)$$

Where $\theta_{\max}$ is the largest permissible lift off angle of the foot (set to 75° in our experiments) and $D_{\max}$ is a pre-determined upper value for the negative value d. The value $D_{\max}$ is determined empirically from a collection of finger walk doing a running gait, which gives very large values of d. (see Figure 12(c)).

Finger Walk Temporal Profile

As the user's two fingers walk across the multi-touch surface, the left and right fingers take turn making contact with the surface. Figure 6(a) shows the actual y coordinate plot of each touch as the fingers move from higher to lower y values over the time t. This plot is called the *finger walk temporal profile* (FWTP) as it displays the way the walking finger is making its way across the y-dimension of the multi-touch surface over a period of time. Each new touch contact is sequentially labeled T_n, where each new touch will increment n by 1. As expected, the n=[1,3 ..] represent the "left leg" and n=[2, 4, ..] represents the "right leg", plotted in green and blue respectively in Figure 6(a).

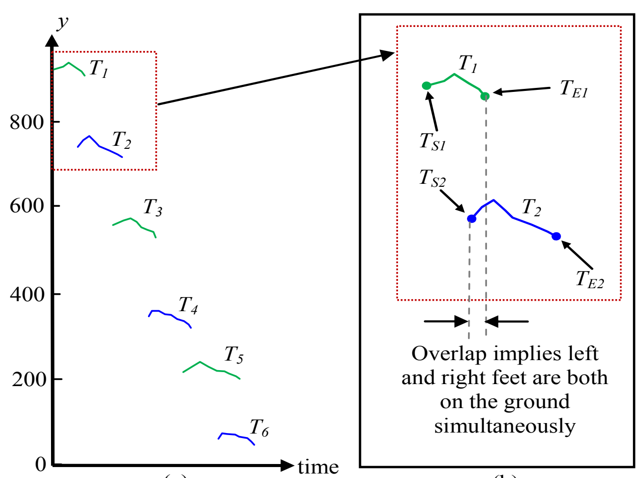


Figure 6. (a) Finger walk temporal profile of a walking gait. Left and right leg in green and blue respectively. (b) Detail view of two consecutive touch profiles and their overlap in time. Start and end times of touch profile given by T_S and T_E.

As shown in the gait analysis of Figure 2, a typical walking gait will have periods where both the left and right legs are simultaneously in contact with the ground. The FWTP of the running and two-legged hopping gaits are illustrated in Figures 7(a) and 7(b).

To model the walking, running and two-legged hopping gaits, two consecutive touch profiles start and end time points must be used (see Figure 6(a)). The gait identity parameter G is given by

$$G = 2 * (T_{En} - T_{Sn+1}) / (T_{En} - T_{Sn} + T_{En+1} - T_{Sn+1}) \qquad (3)$$

The start point of a later touch profile is used to subtract the end point of an earlier touch profile.

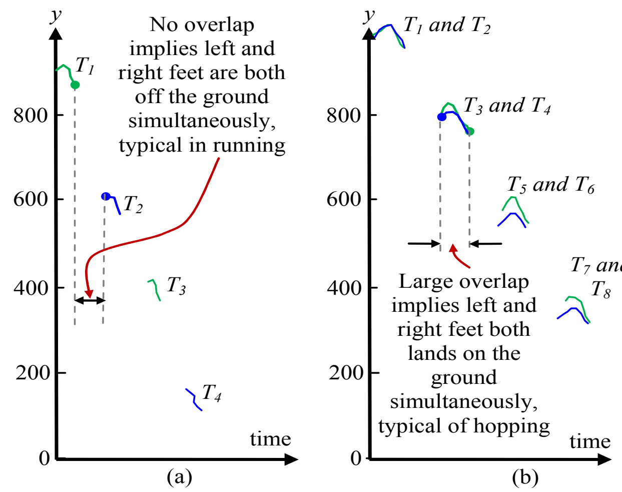


Figure 7. Finger walk temporal profile of the (a) running gait where there is no overlap in time and (b) the two-legged hopping gait where the left and right touch contact are mostly overlapped in time.

Finger Pressure Temporal Profile

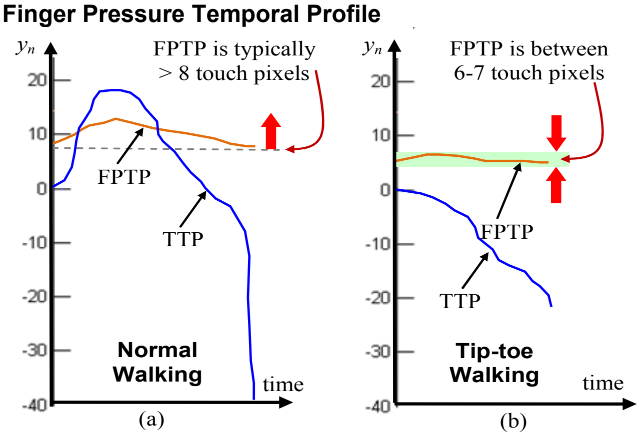


Figure 8. Finger pressure temporal profile. (a) FPTP of a normal walking gait where radius r is usually larger than 8 touch pixels. (b) FPTP of a tip toe walking, where radius r is typically less than 7 touch pixels.

A final temporal profile that is useful for providing some additional human gait control in the values of the major radius value r during the contact period. Figure 8(a) of the *finger pressure temporal profile* (FPTP) shows how the radius r changes with a normal pressure finger walk gesture and Figure 8(b) shows the FPTP where the finger walk is done with a very light touch. We propose using a light touch to signify a gait done with tip-toe.

CLASSIFYING HUMAN GAITS WITH FINGERWALK

The gait identity G given in equation (3) that is extracted from two consecutive finger walk contacts of the left and right or right and left fingers can be used to classify several basic human gait types.

Walking Gaits

The walking gait is characterized by short overlaps between the left and right touch profiles. Using the gait identity G, the typical walking gait is given by

$$\text{WALK} = 0 \leq G < 0.5 \qquad (4)$$

In addition, if the back travel peak value h in Figure 5 is large, this walking gait would have a large heel strike angle and such walking gait is normal done with the knees more bent. We classified as a happy walking gait that is usually done with some bending of the knees and it is given by

$$\text{HAPPY WALK} = 0 \leq G < 0.5 \ \textbf{AND} \ h > 15 \qquad (5)$$

Walking can also be done with tip-toes. We classify a walking gait as being done by tip-toe if the following is observed

$$\text{TIP-TOE WALK} = 0 \leq G < 0.5 \ \textbf{AND} \ r \leq 7 \qquad (6)$$

Running Gaits

The running gait is characterized by regular periods of the suspended phase, in which both feet are momentarily off the ground. Using the gait identity G, the suspended phase can be detected by

$$\text{RUN} = G < 0 \qquad (7)$$

In addition, a fast running gait can be specified by applying more finger pressure on the touch surface while performing the running gesture. The application of stronger pressure and a more assertive finger lift off mimics the stronger leg push a runner has to do in order to run faster or take a longer stride. This increase finger pressure will lead to a higher back travel peak value h. We classify a fast running gait as

$$\text{FAST RUN} = G < 0 \ \textbf{AND} \ h > 15 \qquad (8)$$

Hopping Gaits

Unlike walking and running, hopping is not left-right sequential. Both legs are used simultaneously to move forward. The temporal profile of hopping shown in Figure 7(b) shows that there is extensive time overlaps between the left and right feet. A hopping gait can be detected by using the gait identity G given by

$$\text{HOP} = G > 0.8 \qquad (4)$$

Since hopping is done two feet at a time, once hopping has been detected, the n value is increment by 2 so that a new pair of temporal profiles is analyzed. The hopping gait itself can have some variations. A person may do a long leap or just a short leap like in the normal hop. In order to classify the finger gesture as a long and strong leap, increase finger pressure is again used to specify a long hop and this is classified with

$$\text{LONG HOP} = G > 0.8 \ \textbf{AND} \ h > 15 \qquad (4)$$

Limping Gait

A person will appear to walk with a limp when the movement of one leg appears stronger than the other. Since the stronger foot needs to support the weaker foot, it spends more time in contact with the ground than the other. The limping gait can be defined as

$$\text{LIMP} = (\text{Min}[TL_n, TL_{n+1}] / \text{Max}[TL_n, TL_{n+1}]) < 0.6 \qquad (7)$$

Where the touch profile duration TL_n is given by $T_{En} - T_{Sn}$. The function Min and Max select the smaller and larger of the two lengths, respectively.

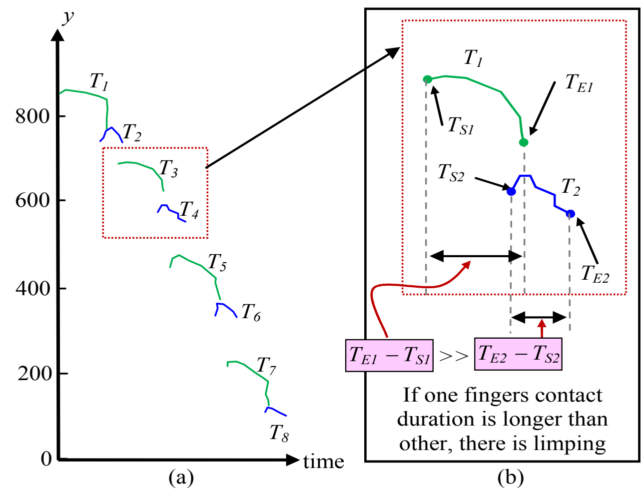


Figure 9. Limping gait where (a) the durations of contact of two consecutive touch profiles are very different. (b) The parameter to compare to classify limping

ANIMATING THE TWO FEET

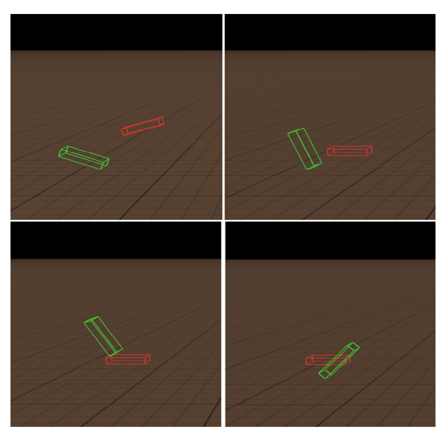
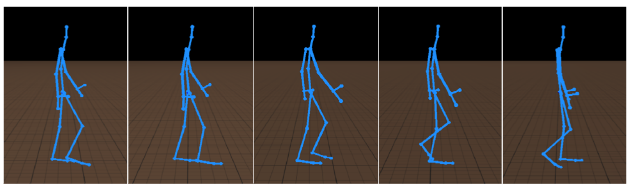


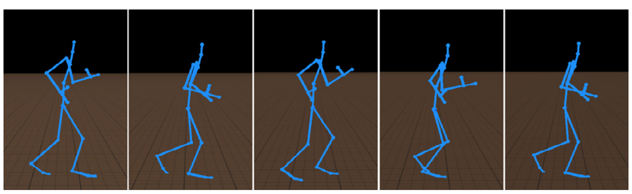
Figure 10. The two cuboid feet animation sequence showing a typical heel strike sequence created by doing a walking gait gesture using FingerWalk. (see video)

FROM FINGER TOUCH TO FULL BODY MOTION

We use a simpler version of an example-based animation engine [28] to generate full-body motions for the avatar from gait parameters extracted from finger touches. Different types of example gaits in different direction and speed were first captured from an optical motion capture system. For instance, we captured two walking motions that matches the WALK and HAPPY WALK classifications given by equations (4) and (5). We then need to process the motions so that they are suitable for online interpolation and blending. First we extract the most cyclic cycle from each example motion and make it perfectly cyclic by distributing the difference between the first and last frame into the full cycle. We then align the cyclic motions of the same type in space so that they all start from the world origin and move along the same direction. Lastly we normalize the cycles in time so they have the same duration.



(a)



(b)

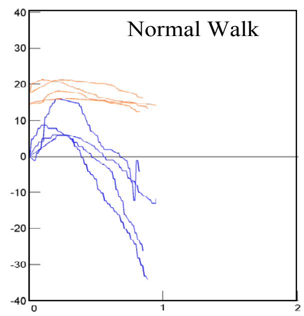
Figure 11. Full body animation control using the finger walk classifications for (a) WALK in equation (4) and (b) RUN in equation (7). (see video)

At runtime, we select the two motions that have the closest step lengths to the required step length. From these best matching motions we use linear interpolation for the kinematic root (pelvis) and spherical linear interpolation for all the joints to generate locomotion of the new step length. We then resample the interpolated gait to match the desired step duration. The root of the character should be translated and oriented to where the last step ends so that the virtual character can move about continuously within the virtual environment. To transition smoothly between different gaits, we use linear blending while enforcing a fixed-point constraint for the stance foot to avoid unnatural foot sliding.

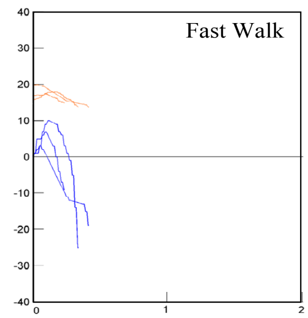
Figure 11(a) and (b) shows sequences of a full body animation of the normal walking gait and running gait respectively.

USER STUDY

A user study involving 4 participants was conducted to observe if the finger walk patterns for different specified gaits would produce reasonably similar touch traversal profile. Two males and two females from ages 22-25 years were asked to perform finger walk gestures for normal walking, fast walking, tip-toe walking, running and hopping. For each of the five gaits, each participant were asked to perform the gestures twice. Before doing so, each participant was given a brief demo of how each finger walk gesture has to be done to produce the specified gaits. They were then asked to perform all the required gesture in one sitting. All touch points were recorded in real-time and stored for later analysis.



(a)



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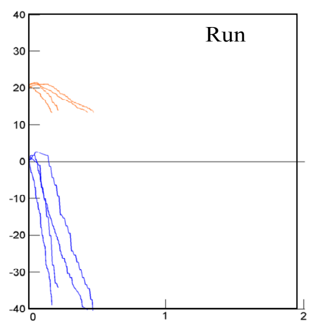
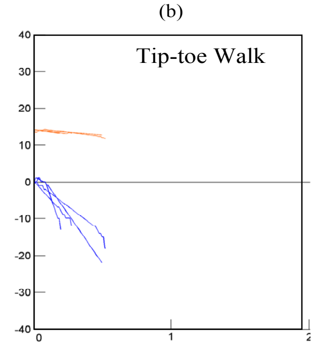


(c)



(d)

Figure 12. Results from the user study. The plots show the multiple overlaid touch traversal profiles of all attempts by every user. A suitable offset was added to the orange r values of the FPTP for better visualization. The gaits representing the plots are (a) normal walk, (b) fast walk, (c) run and (d) tip-toe walk.

The touch traversal profile with the most variations is that for normal walk. The variation in the back travel peak h was quite substantially and would have affected the initial angle of the heel strike foot landing. This is due the the pressure variation each user may use when performing the finger walk gesture. However, these variations are not of great concern because initial heel strike angles do vary greatly from person to person when they walk. Even the same person will vary this aspect of his walking gait depending on whether he is tired, moody or energetic.

Overall, the touch traversal profile for all the other three gaits is reasonably consistent. This suggests that the finger walk gestures on multi-touch tablets may have the potential for more universal adoption as a convenient means for end users to control gait nuances of their avatar as they navigate in virtual worlds and interact with other avatars.

LIMITATIONS AND FUTURE WORK

As a proof of concept, we currently use a simple Inverse Kinematics engine to solve for full-body animations. In the future, we would like to connect to more powerful data-driven animation engines [4, 13] or physics-based locomotion engines [6]. All the gaits we extract from finger touches are straight line locomotion. It would be interesting to investigate the possibility of turning with fingers. This may be challenging because of the biomechanical constraints between the two fingers and the inherent ambiguity between turning and moving diagonally just from the finger touch positions.

Another interesting area is to apply this technique to animate non-human characters. For example, the penguin in the movie Happy Feet, with its short stubby legs could be an interesting character to locomote with FingerWalk.

CONCLUSIONS

We have presented a method to use finger touches to specify parameterized gaits and locomotion control for virtual characters. Even though finger walking and foot walking are not entirely identical kinematically and dynamically, we found it natural and intuitive to use fingers to imitate different locomotion styles. From our user study, it was observed that the variations in finger walk patterns do not vary very much among the four participants, which suggest that with some brief instructions about how finger walk can be used to specify different gaits, users can quickly produce reasonably consistent signals, which will be able to the animate their respective avatar in the desired manner.

Much work remains to be done as the repertoires of gaits we can currently control are rather limited. Incorporation of subtle foot strike modeling needs to be further refined to better conform to physiological constraints of human locomotion. The idea that the ubiquitous multi-touch tablet PC can be used to control the gait of human avatar in virtual worlds is a novel one and can potential provide a affective means to communicate subtle body languages in the virtual world.

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Image taken from FreeDigitalPhotos.net by N. Apikhomboonwaroot.

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