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AUTONOMOUS QUADRUPED ANIMATION TECHNIQUES: A SURVEY

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ABSTRACT

Computer generated animation has become extremely popular in current era involved not only in movies and games, but mainstream television, education, scientific visualizations, Sports are but few noteworthy areas of its application. Even though majorly two types of animation techniques are used in the general industry; namely key-frame and motion capture, there are various other techniques of generating autonomous animation. In this survey paper we discuss the major techniques and approaches towards procedurally generating autonomous animation of Quadruped characters in specific. Initially we discuss various techniques used in generating skeletons and creating a character rig for quadrupeds. The various animation techniques are then discussed from footprint generation to data driven methods and finally physics and dynamics based approached and algorithms. All these methodologies tend to provide best possible solution for solving the problem of generating involuntary and autonomous animation of quadruped characters. In the end, a more suitable hybrid technique is proposed which will be more practically feasible and user friendly so it can be easily implemented.

Key Words: Quadruped Animation, Character Rigging, Footprint, Data, Driven, Motion Capture, Physics based simulation.

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1. INTRODUCTION

Computer generated animation has become extremely popular in current era, involved not only in movies and games, but mainstream television, education, scienti?c visualizations and sports are but few noteworthy areas of its application. Even though major two types of animation techniques are used in the general industry; namely key-frame and motion capture, there are various other techniques of generating autonomous animation. In this article, the major techniques and approaches are discussed towards procedurally generating autonomous animation of Quadruped characters in speci?c. The numerous animation techniques are then discussed from footprint generation to data driven methods and ?nally physics and dynamics based methods and algorithms are reviewed. All these methodologies tend to provide best possible solution for solving the problem of generating involuntary and autonomous animation of quadruped characters. In the end, a more suitable hybrid technique is proposed which will be more practically feasible and user friendly so it can be easily implemented.

Various techniques of animating virtual biped and quadruped have been researched and discussed since last two decades. The repertoire of animation techniques involve Physics & Dynamics based techniques, Data Driven or often known as Example based techniques, Motion Capture and Sensor driven animation, and Procedural Animation Techniques. These various techniques of generating real-time animation differ in the trade-off the offer between the control that can be exerted over the motion, the motion naturalness, and the required calculation time (Van et al., 2010). Hence each technique with its implementation and its usability aspects is dependent on the requirements of the researcher developer or application customers.

2. PROCEDURAL ANIMATION TECHNIQUES

Quadruped motion has always been an integral part of character animation and simulation. Various techniques and approaches have been used to understand the realistic motion gaits and parameters of quadruped animals. The initial work of recording and documenting animal motion gaits was done by Eadweard Muybridge (Muybridge, 2012a; Muybridge, 2012b) using set of 24 cameras. The rich and diverse history of quadruped animation and motion synthesis is intensely discussed by Skrba et al. (2009b) in their state of the art report “Animating Quadrupeds: Methods and Applications”. Skrba discusses several ways for achieving realistic quadruped motion, through “video-based acquisition, physics based models, inverse kinematics, or some combination of the above” (Skrbaet al., 2009b).

2.1 Footprint based Animation

One of the initial works done, with regards to Footprint based animation, is by Panne (1997). He discussed a footprint based biped animation system with optimization process to increase the plausibility of physical locomotion with perceived comfort. The locomotion system is however dependent of user input of actual footprint locations and their relevant timing information. The motion is perceived as centre of mass (COM)

Similarly, Torkos also discusses the same hybrid technique with physics and kinematics based footprint dependent animation system for quadrupeds (Torkos and Panne, 1998; Torkos, 1997). They use an optimization technique based on spline trajectory with hard and soft constraints to synthesize quadruped motion. The constraints consist of footprint locations along with their timing information as hard constraints and physics based soft constraints. This combinational technique of synthesizing motion represented using spline trajectories that derive the state of the quadruped footprint motion over time, successfully generates various motions such as walking, jumping, galloping etc.

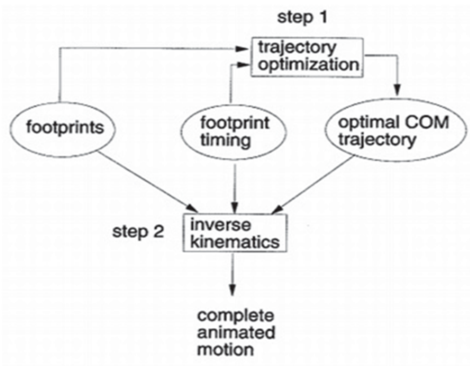

Figure 1: Footprint based motion synthesis

In a more recent attempt, Egges and Basten(2010) describe several techniques and methodologies of using footprints to generate and synthesis Biped motion in real- time

Initially Basten et al. (2010) describe a novel technique based on The Step Space to create a biped motion using example abased footprint information to synthesis motion (Basten et al., 2010). Then extending this technique, Egges&Basten (Egges and Basten, 2010) discusses another approach termed as “One step at a time” to animate virtual biped characters using footprint information in real-time. This approach uses greedy nearest-neighbour algorithms to produce human locomotion, dependent on footprint locations using spatial and temporal constraints. They implement a unique side stepping technique, of the feet’s motion, along with regular motion using a simple footstep path planner system. These footstep based techniques are even further extended to develop a hybrid interpolation scheme for generating human walking motions driven through footprint information (Basten et al., 2011). The motion synthesis technique, of human walking, is achieved by combining Cartesian and rotational interpolation to generate the plane parameterized stepping motions.

However, all these footstep or footprint driven techniques are used to generate and synthesis Human or Biped motion only. Other noteworthy works which generates motion through footsteps or footprint information are (Bouyarmane and Kheddar, 2012; Hugel and Jouandeau, 2012; Dong, D., 2012; Schmitz et al., 2012; Weijermars, 2010; Wu et al. 2008; Yin and Pai, 2003).

2.2 Kinematics based Animation

In 3D computer graphics area, the Inverse Kinematics (IK) based approach for leg transformation is used widely as discussed by (Kokkevis et al., 1995; Torkos and Panne, 1998), where the placement of the foot is decided ?rst and then physics based model drives the body. Curtis et al. (2011) uses a “biomechanically-inspired, kinematic- based, example-driven walking synthesis model”. The technique involves example driven model to interactively synthesize the walking motion, with- out any prior information or knowledge of the motion trajectory of biped characters. Similarly, Tolani et al. (2000) introduces various algorithms of inverse kinematics for manipulating an anthropomorphic arm or leg. The algorithm combines the numerical and analytical techniques to address the problem of generalized inverse kinematics for controlling the position, orientation and aiming constraints. Whereas, Zajac, J. (2003) uses simple mathematical expressions to control the cyclic motion oh human biped in Maya software. The skeleton of biped mesh is driven through inverse kinematics based controllers with trigonometric sinusoidal equations to generate the motion curve. Similarly, Bhatti et al., (2013a) also discusses mathematical procedural generated animation techniques using sinusoidal trigonometric equations and function to generate the periodic wave motion of quadrupeds (Bhatti et al. 2013a; Bhatti et al. 2013b; Bhatti et al., 2015).

2.3 Rule Based Techniques

Standard Procedural Animation techniques involve using standard mathematical and trigonometric based equation and algorithms to generate basic locomotion of virtual characters. These techniques do not involve physics based simulation and are not dependent on data driven techniques. A. Romney (2013) implements Periodic and Coherent Noise interpolation technique to generate procedural animation of a quadruped horse character. The periodic functions were applied on each limb to incorporate various locomotion types. Such type of approach doesn’t require any user intervention, and is less complex then physics and dynamics based simulation techniques. Alternatively Duane et al. presents an intelligent control system with unique rule based approach of heuristic knowledge to generate quadruped motion instead of using any physics or mathematical model (Marhefka et al., 2003).

2.4 Hybrid Animation Techniques

Kokkevis et al. (1995) develops a hybrid quadruped animation system by combining kinematics, dynamics and control theory to generate realist autonomous animation of four legged animals illustrated in Figure (2.7) (Kokkevis et al., 1995). The proposed hybrid system contains Dynamic controller consisting of body and legs subsystem. Gait controllers, based on kinematics, controls the legs subsystem and drives the motion of each leg. The upper body motion is controlled using dynamics, and generated using aggregate force Fr and torque Tr, dynamically with respect to centre of gravity, velocity, angular velocity, position and orientation of the body. The feedback controller is used to calculate the aggregate force and torque vector using desired velocity and animal heading. Then linear programming is used to propagate this fore and torque to the legs subsystem when in contact with ground. This autonomous hybrid approach simulates quadruped motion at varying speed with walking and trotting motion, on even as well as uneven terrain.

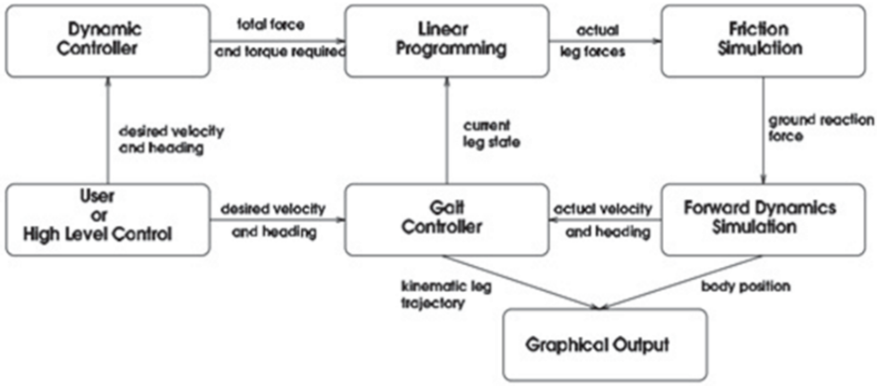

Figure 2: .Hybrid system overview for autonomous animation of Quadrupeds

Shapiro and Pighin (2003) develop a framework by combining kinematics with physics to simulate interactive animation of virtual characters. Using this hybrid technique the 3D human is able to react in unexpected situations using physics based dynamics and maintains natural looking gaits through kinematics.

3. DATA DRIVEN OR EXAMPLE BASED TECHNIQUES

One of the most common techniques for generating autonomous animation of virtual characters is through the means of motion capture or data driven or Example based techniques. These techniques involve several means to obtain the information of real life characters motion for example by observing real life characters in real environment, using high dentition cameras or often through high frame rate based slow motion cameras or sensors to monitor and record the human or animal locomotion characteristics.

3.1 Motion Capture Animation

Most of the high end production studios have vigorously started taking maximum advantage of motion capture technology to record and capture the actual live motion of real character and directly transfer the same into a virtual character in 3D space. Lots of literary work exists in this regard but unfortunately most of this work concentrates on Human or biped characters and very little information are available with respect to quadruped characters. This is due to the fact that, obtaining motion capture data from a four legged animal is quite dif?cult and only few well trained animals like horses, and dogs have been widely used for this purpose (Skrba et al., 2009). Moreover, the motion capture data obtained from one animal can hardly be transferred to other as each animal has its own characteristic and motion behaviours.

joins those motion clips together to obtain ?nal complete animation sequence (Beaudoin and Poulin, 2008; Heck and Gleicher, 2007; Kovar et al., 2002; Reitsma and Pollard, 2007). Kovar et al. (2002) develops a novel technique of generating a realistic and controllable animation sequence, using prebuilt corpus of motion capture data of an individual character. Using this motion data, a Motion Graph system is automatically created, which is a directed graph encapsulating the connections between the motion gaits.

3.2 Video based hybrids

As the problem of handling wild animals is common to all, such animals pose a major challenge when it comes to capturing their motion using sensors. Thus another common data driven technique used for such situations is to extract gait information from the multitude of video source and reference libraries available. Generally two types if techniques have been adopted in this regard: Standard Tracking and Statistical Analysis. Initially the problem of identi?cation and classi?cation from the various video footage sources was presented by Calic et al. (2005). they discuss various approaches towards the processing of videos, ?nding patterns within individual video frames and ?nally classifying the motion information.

Wilhelms andVan Gelder (2003) discusses a method of extracting horse motion information from a video source. This motion information is then applied to 3D model of a horse character. The system uses active contours of 3d model and video source are matched and anchored together. As the Video is played, the contour lines from the video frame are changes, which conversely drive the contours positions of the horse skeletal mesh as shown in Figure (2.8) (Wilhelms and Gelder Van, 2003). Similarly Agarwala et al. (2004) discusses 'roto-curves' instead of active contours as in (Wilhelms and Gelder Van, 2003). The roto-curves are used to mark the outline of key area of interest in a video footage which then are used to drive the animation as Figure (2.9) (Agarwala et al., 2004).

Figure 3: Error! No text of specified style in document. Horse model is the same size as the one in the video. The active con- tours are anchored to the model so it follows the horse in the video (Wilhelms and VanGelder)

Figure 4: Error! No text of specified style in document. Roto-curves are used to outline areas of interest

However, Gibson et al. (2005) implements a tracking system to capture and record specific point of interest of very small insects such as spiders and ants, using three cameras. Contrary to this, Favreau et al. (Favreau et al., 2004; Favreau et al., 2006) uses a Statistical analysis approach to analyse video data and use the information to generate 3D motion of virtual characters. A Principal Component Analysis (PCA) technique - initially proposed by Turk and Pentland (1991), is applied directly on all the segmented images of the video sequence to ?nd patterns of regular motion in images. This information is then processed to predict and generate the 3D motion of various animals using Radial Basis Functions (RBF) as illustrated in Figure (2.10) (Favreau et al., 2004).

Similarly, Gibson et al. (2003) implements PCA on video footage of walking animals in an outdoor environment. Hannuna et al. (2005) discusses the similar PCS based approach to identify and extract animal motion information from various wildlife videos.

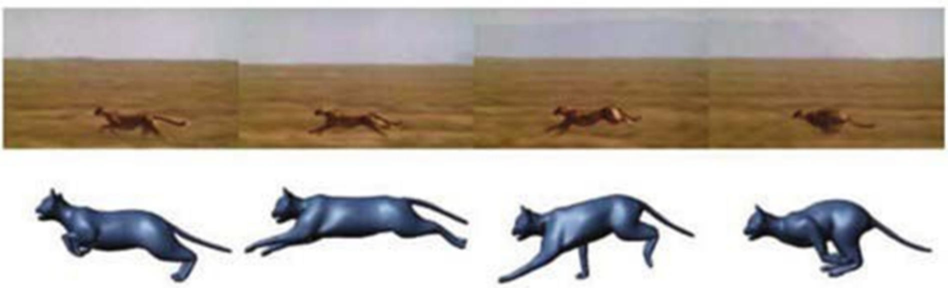

Figure 5: Error! No text of specified style in document.Images extracted from a video are used as a learning set for prediction of continuous 3D motion

Ramanan and Forsyth (2003) used a technique of directly representing an animal's appearance as a 2D model from a video footage. The main pool of pixels was identi?ed as the animals within each frame, which then were used to derive the 2D appearance of animals.

3.3 Motion Synthesis

Huang et al. (2012) discusses a locomotion synthesis approach for a Horse Character with user interaction. Horse locomotion data was obtained from E. Muybridge's book (Muybridge, 2012a; Muybridge, 2012b), along with motion capture data. The proposed asynchronous time wrapping method automatically synthesis the root trajectory of the horse character, adjusting orientation of the body, driven through direction of the horse turning motion. This allows the variation in gaits, based on the speed of motion at runtime.

In more recent attempt, Junze Zhou (2013) uses a perception based in- formation to procedurally generate quadruped gaits. The system provides a user controlled GUI, which builds and synthesize the cyclic gaits for quadruped animation, along with skeletal rigged structure which attempts to communicate weight and age of each animal character.

4. PHYSICS AND DYNAMICS BASED TECHNIQUES

Physics based animation techniques involve generating autonomous animation of virtual characters using physics and dynamics based properties that adhere to real world principles. Such type of animation techniques that use forward dynamics and physics involve implementation of various real world forces with torques and gravity. The motion is derived through principle of velocity, momentum, weight and mass of the body, along with various other principles and factors that affect the motion of moving bodies in real world. The main advantage of such type of technique is that of realism and accuracy of generated motion, but however this approach also lacks the user interaction and controllability aspect as well.

4.1 Physics based techniques

3D forward dynamic simulations of quadruped gaits are introduced by Raibert (1990), who developed control strategies for trotting, bounding, and galloping gaits for a robot quadruped with a rigid body and extensible legs (Raibert, 1990). The movement of the character is controlled by a system that integrates equations of motion derived from physical models. Similarly the game of Spore by Hecker, develops methods for generating procedural animation for arbitrary legged creatures, including locomotion patterns (Hecker et al., 2008).

Marsland and Lapeer (2005) discuss generating physics based autonomous animation technique in real time, especially focused on a trotting horse motion. The methodology reduces the user intervention and positions each leg of horse accurately by using video footage as a guidance mechanism. The horse skeleton, modelled as connected bodies effected by physics principles (like gravity), is created using hinge joints with limit set to degree of freedom of each joint based on horse motion analysis done from various video footages of horse. The optimization and error minimization is done through P-Controllers. On the other hand, Wampler and Popovi(2009) developed a two-level optimization procedure for physics-based trajectories of periodic legged locomotion and use it to explore connections between form and function. Whereas, Kwon and Shin (2005) have analysed the centre-of-mass trajectory of human walking and running motions to segment unlabelled motion sequences into motion half-cycles.

On the other hand,Coros et al. (2011) in his paper discuss physics based simulation centred on integrated set of gaits and skills covering a wide range of motion repertoire of a dog. Coros et al. (2011) implements a Jacobian transpose and proportional derivative (PD) controller system for generation locomotion of quadrupeds with virtual forces and gait optimization to achieve realistic set of gaits and styles for physics based dog character. Figure (2.11) (Coros et al., 2011) shows the structural overview of the quadruped simulation system.

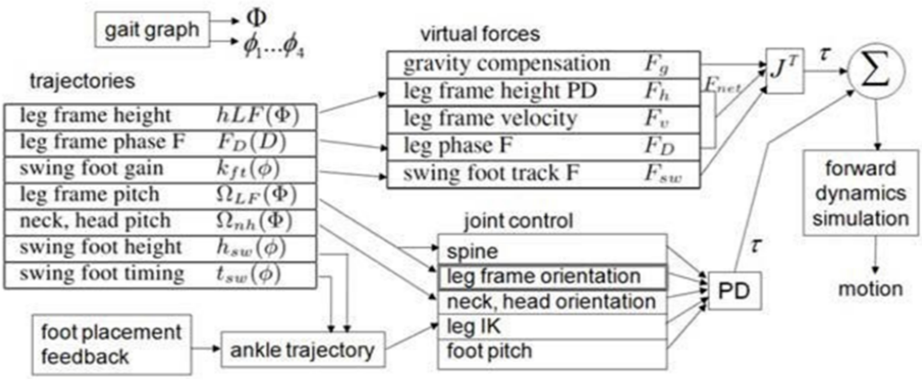

Figure 6: Error! No text of specified style in document. A structural overview of the various components of the quadruped controller

4.2 Interaction and Behaviour

Most physics and dynamics based techniques produce realistic looking animation of virtual characters, however the fail to provide direct user control and interaction in the process. Martin and Neff (2012) introduce a new methodology of providing interaction to 3D characters animations with a system called Cat Animation Tool (CAT). The system aims at novice animators to be able generate basic quadruped animation quickly using through type of controllers applied on house cat model as shown in Figure (2.12) (Martin and Neff, 2012). An input curve is used initially, with motion driven through kinematics to create locomotion. The controller at topmost level is an algorithmic controller responsible for generating basic locomotion. The middle level controller is multi-joint which controls appendages of cat model. At the end, single-joint controller is used for the ?nest and direct control over the joints.

Tomlinson and Blumberg (2003) used arti?cial intelligence with machine learning, multi-agent coordination and motor control, to bring their virtual wolf character to life. Behavioural properties of a real world wolf were hard-coded in the system, along with learned behaviours which gave the 3D model reactive capabilities in its environment. This resulted in various random simulations of wolf characters that changed their motion as time passed by.

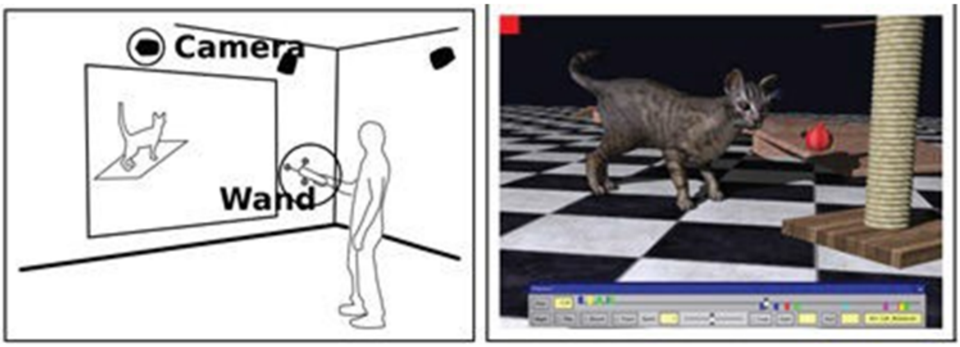

Figure 7: Error! No text of specified style in document.Physical workspace and picture from CAT animations

Hecker et al. (2008) describes a highly unique approach of animating diverse characters whose morphologies are not know initially. The user creates animation using the familiar techniques, then the system, generalizes the animation data to a speci?c character at runtime. Whereas Laszlo et al. (2000) proposes user interactivity with user-in-the-loop technique applied on various physics based characters. The animation of virtual characters is controlled by mouse and key- board, which serves as the primary user inputs. As illustrated in Figure (2.13) (Laszlo et al., 2000). B. J. Rusnell (2000) Implements the work done in (Laszlo et al., 2000).

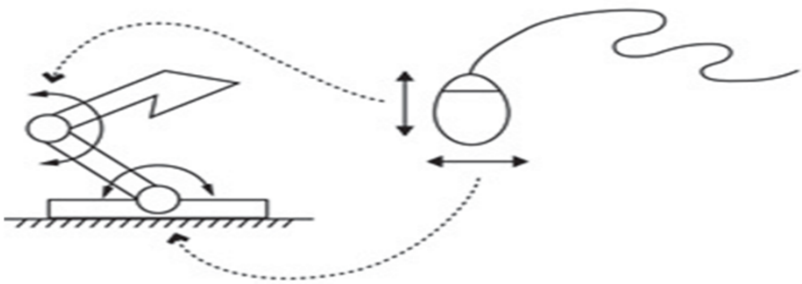

Figure 8: Error! No text of specified style in document.Interactive control for Luxo, the hopping lamp

5. MESH DEFORMATION AND ANIMATION

All of the previous procedural or data driven techniques discussed so far, uses some form of skeletal structure to drive the animation. In an alternate approach, the actual polygonal mesh itself has also been used by various researcher for animation output

(James and Twigg, 2005; Shi et al., 2007; Walter et al., 2001). Whereas Kry et al. (2009) in his paper discusses the use of model deformations to generate the gait patterns to achieve motion. On the other hand, James and Twigg (2005) implement "proxy banes" instead of actual skeletal bones to deform the skin of an object for animation as shown in Figure (2.14) (James and Twigg, 2005).

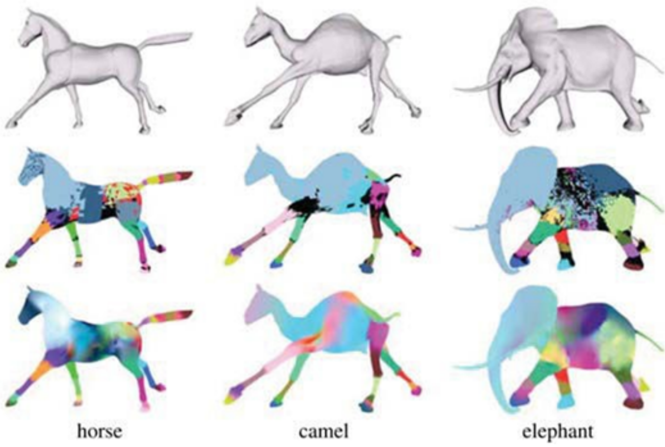

Figure 9: Error! No text of specified style in document.(Top) the triangle mesh, (middle) estimated bones, (bottom) vertex weighting to the virtual bones

Der et al. (2006), considering the fact that neighbouring vertices tend to move together, to deform the 3D mesh. This reduces the complexity and makes it easy for the user to animate the 3D character. Whereas Shi et al. (2007) speci?es constraints on each leg to preserve its length, ?xation of the foot on the ground, balance preservation and self-collision. Through these constraints and limitations, the shape and volume of the deformed mesh are maintained as shown in Figure (2.15) (Shi et al., 2007).

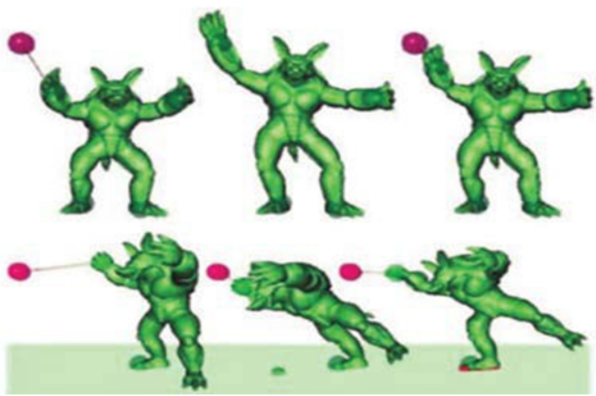

Figure 10: Error! No text of specified style in document.Mesh Deformation system using various constraint

6. RESULT & DISCUSSION

6.1 Proposed Footprint Based Hybrid Animation Technique

The major issue with current system of generating procedural animation is of controllability. With physics based system of procedural animation, the character's motion cannot be controlled and modified or altered directly, as it is driven through virtual forces and torques. Further, as each individual character has its own style and personality which is usually shown through their motion i.e. walking style. This can also reflect the mood of character and his feeling or thought. For example if he is sad then he may walk slowly with depressed look and feel to his walk style. This property cannot or is hardly ever addressed in physics based procedurally generated dynamic motions. The motion capture or data driven techniques are also dependent on the type of motion provided and can only work on that. Moreover these techniques require expert with technical knowledge of the motion capture system. This proves to be a problem for the novice animator.

Contrary to these techniques discussed, we propose a Hybrid Mathematical based Procedural animation technique. Our proposed methodology is to use rule based mathematical formulae to drive the kinematics based limbs of the character. The footfall and footstep based algorithm will control the exact foot placement during various gaits and optimization with synthesis algorithms will be used between gait transitions. A higher level user control mechanism is provided through Graphical user interface to control and modify the animation of quadrupeds at runtime.

CONCLUSION

In this paper a detail review of various quadruped animation techniques was discussed. Quadrupeds being the most profound characters types possess a huge share in the animation industry and thus are also extensively researched. The most widely used animation approach is based on Data Driven techniques, involving motion capture based animation. In such methods, sensors are normally used to detect the motion parameters of live characters and then these parameters are transferred onto virtual 3D models. The other common technique in the same category is video based technique, where the motion and gait information is extracted from a 2D video footage source. The physics and dynamics based technique has also became quite popular regardless of them being computationally extensive and require professional programmers at the back end. Such type of animation is widely being used in game industry were user intervention controls the behaviour and gaits of virtual characters.

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