Kinect controlled dinosaur simulations for education and public outreach

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Abstract

Dinosaurs are a source of enormous public interest and as such are useful for fostering greater interest in basic science and technology. With the increasing popularity of dinosaur films that claim to portray realistic dinosaur behaviour, one question that is regularly posed for palaeontologists to answer is how we know that our reconstructions are accurate. Dinosaur locomotion is no exception to this line of questioning and one technique for estimating how dinosaurs may have moved is multibody dynamic simulation (MBDA) of high biofidelity musculoskeletal computer models. Such simulations uses Newton's Law's of Motion to calculate how the different parts of the animals body would have moved depending on the internal forces generated by the muscles and the external forces due to gravity and physical contact with the ground. In this project we designed a system that allowed the user to directly control the muscles forces generated using a Kinect for Xbox One sensor attached to a PC using the Kinect Adaptor for Windows. The Kinect output is used to drive the muscles using customised software and models (*Tyrannosaurus*, *Triceratops*, *Brachiosaurus*, *Edmontonia*, *Edmontosaurus*, *Gorgosaurus*) based on our standard GaitSym MBDA system. The initial system was trialled over 7 days at the 2015 Cheltenham Science Festival which showed that the bipedal models were relatively easy to control using human body movements and provided a good vehicle to explain how the physics and physiology behind dinsoaur locomotor reconstruction. The quadrupedal models in their current form are much more difficult to control and further work is needed in this area. The 3D models and software for this project are freely available to download (http://www.animalsimulation.org or DOI: 10.6084/m9.figshare.2008977) and it is hoped that they will find further uses in areas such as 3D printing for anatomical education and virtual world simulations.

Introduction

Promotion of STEM subjects through public engagement in science is part of current UK government policy [Department for Business Innovation & Skills, 2015] and science festivals are one popular approach for achieving this goal [Jensen and Buckley, 2014]. Digital approaches in palaeontology are an important medium through which to communicate information concerning contemporary scientific issues [Bates et al., 2009] and the goal of this project was to produce an interactive, educational exhibit featuring cutting edge computational techniques that could be used in the context of science festivals and other educational venues such as events at museums or school visits. We have been working for a number of years on the use of evolutionary robotics as a way of reconstructing the locomotor capabilities of fossil animals [Sellers et al., 2005; Sellers and Manning, 2007; Sellers et al., 2013] and have produced an open source simulation software package, GaitSym (http://www.animalsimulation.org) to do this. This software is able to solve moderately complex musculoskeletal multibody dynamic simulation systems in real time and so is eminently suitable as a base for an interactive exhibit. Multibody dynamic simulation is an engineering technique for solving the equations of motion of linked rigid body systems and has been used as a tool for understanding the biomechanics of vertebrates for a number of years [Sellers, 1996]. There are a number of different physics simulation libraries available that implement this approach for use in robotics and computer games with very similar performance characteristics [Peters and Hsu] and these can be coupled with a custom written front end to allow straightforward simulation of complex biological systems. The Microsoft Kinect for XBox One (http://www.xbox.com) is a real time game controller that works as a 30fps laser range camera which can be attached to a Windows PC using the Kinect Adaptor for Windows. This sensor has already found a number of uses within biomechanics research [Oikonomidis et al., 2011; Auvinet et al., 2015] and therefore this combination of technologies is ideal for producing a simulation system that can demonstrate how modern computational techniques and a knowledge of physics, physiology and anatomy can be used to predict how dinosaurs could have moved. The Microsoft Kinect for XBox One can be attached to a Windows PC using the Kinect Adaptor for Windows and programmed using the Kinect for Windows SDK 2.0 (http://www.microsoft.com). The current version, unlike earlier versions, is heavily tied to the Windows platform and there is no current support for other operating systems. The SDK allows the raw depth map to be read, but also includes support for fitting a series of up to 6 figures to the depth data and the estimated joint and segment positions can be read directly. These joint positions can then be used as controllers in the GaitSym model and can therefore drive the muscles directly to allow movements in the users body to control the dinosaur simulation.

Implementation

The first step in creating a musculosketelal multibody dynamic simulation is to create an anatomical model. These were created initially by hand in Cinema 4D (http://www.maxon.net) based on a range of sources (photographs, anatomical illustrations, laser scans and photogrammetry) and then imported into Blender (http://www.blender.org) where the neutral posture was defined. The dinosaurs chosen were to cover a range of well known (*Tyrannosaurus*, *Triceratops*, *Brachiosaurus*) and less well known (*Edmontonia*, *Edmontosaurus*, *Gorgosaurus*) taxa. The models are deliberately generic representing a consensus reconstruction with smoothed morphology, particularly in repeating elements such as vertebrae and ribs. These models should probably be scaled to represent a specific specimen and checked for accuracy against more detailed scans and measurements if they are to be used scientifically. The anatomical model defines the limb segments, joints, and substrate contact elements following our standard protocol for quadrupedal models [Sellers et al., 2009] and listed in Table 1.

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Joint	Proximal Segment	Distal Segment
Hip	Trunk	Thigh
Knee	Thigh	Shank
Ankle	Shank	Foot
Shoulder	Trunk	Arm
Elbow	Arm	Forearm
Wrist	Forearm	Foot

Table 1. The joints and rigid segments defined for the dinosaur models

The second step is to calculate the mass properties of the model. To do this we create convex hulls for each of the rigid segments and allow GaitSym to calculate the mass properties based on the hull and a nominal density of 1000 $kg.m^{-3}$. As discussed previously [Sellers et al., 2012] obtaining the best possible mass estimate requires somewhat more work but this simplified approach will provide an approximate mass value that will allow the simulation to function properly and as we have shown previously [Bates et al., 2010] absolute mass makes relatively little difference to the results of multibody dynamic gait simulations. The third step is to rig the skeleton with appropriate muscles and we do this following the simplified pattern we have used previously [Sellers et al., 2013] using standardised scaling factors to calculate the muscle mass. The calculation of muscle parameters requires us to define the range of motion available at each of the joints which is done based on the anatomy. The range of motion is checked against the minimum muscle mass required and reduced if there is a large mismatch between the muscle mass available and the minimum muscle mass required [Sellers et al., 2013]. The final step is to convert the model to a form that is suitable for direct control by the Kinect.

The current version of the software hard codes the reading of the Kinect interface. The joint angles are extracted from the human figure generated by the Kinect SDK API and simply thresholded. If the angle is above the threshold then the appropriate driver in the GaitSym model is activated, and if below the threshold then the antagonistic driver is activated. This very simple approach works remarkably well since the user does not expect the dinosaur to adopt the same posture as they do but to match the movements that they make so absolute positioning is not required. The other feature that is needed in the models is something to make them more stable. There are a number of possibilities depending on what ultimate movement is required. If the simulation is to be held static and the limbs simply moved as might be done with human musculoskeletal simulation in order to demonstrate how the activation of particular groups is associated with particular movements then this can be achieved by simply using a fixed joint to attach the trunk to the world. However if the simulation is to progress forward powered by the movements of the user then a limited amount of controlled movement is required. Our current approach here is to create an invisible extra segment that is attached to the world by a horizontal linear sliding joint. This slider is then attached to the trunk of the dinosaur by four elastic 'skyhook' elements. These hold the trunk up rather like a marionette and allow realistic looking movement without overly restricting the simulation. The stiffness of these elastic elements is something that needs to be hand tuned for each model so that the model's movements when controlled by the user work well. The final models are illustrated in Figure 1.

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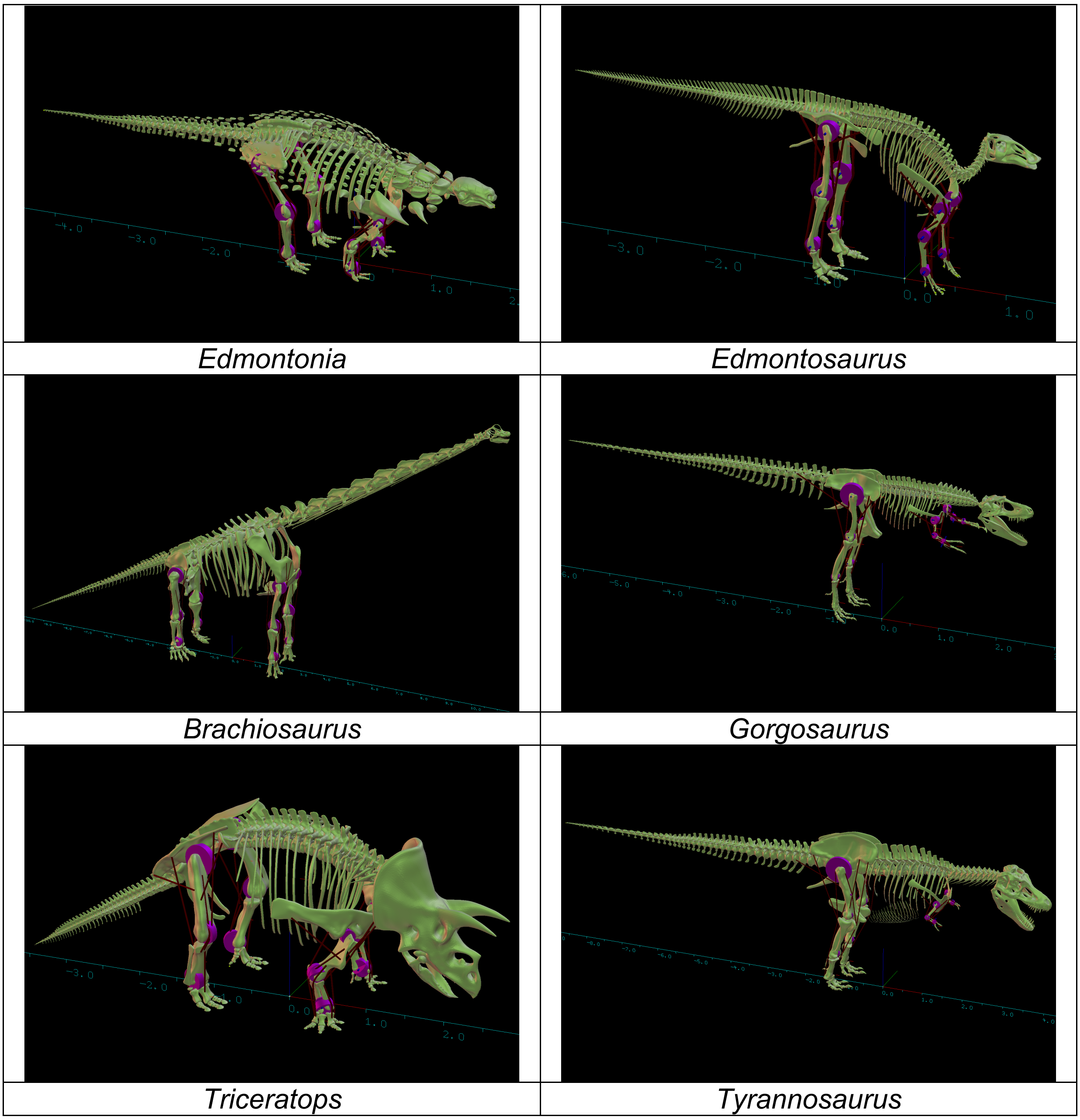

Figure 1. 3D models created for the dinosaur simulator. The values on the scale are in metres.

Observations in Use

The initial system was trialled over 7 days at the 2015 Cheltenham Science Festival. The setup involved mounting the Kinect on a photographic tripod and displaying the simulator and the raw Kinect output on the computer monitor (Figure 2). During this time, over 500 people used the exhibit ranging from young children to adults. The Kinect system works extremely well and generally was able to lock onto the closest person to the sensor. Once locked on most people managed to learn to control the dinosaur and could manage to drive the simulation forward slowly. There were some difficulties though due to the way that the Kinect sensor works. This meant that

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visitors whose clothes hid their knees from view were not tracked properly and this led to erratic control. In addition when the exhibit was busy it was very important to maintain sufficient space around the sensor so that the system could lock clearly onto a single person. It was essential that the exhibit was manned at all times both to ensure that the purpose of the exhibit could be explained and also to demonstrate how the control system worked. In particular users tend to get too close to the Kinect sensor and it has a minimum distance of approximately 1m if full body tracking is wanted. The bipedal models were relatively easy to control using human body movements and provided a good vehicle to explain how the physics and physiology behind dinosaur locomotor reconstruction. In particular it was useful to explain how the body shape in the dinosaur was different from a human and how this means that different movements are required to ensure the simulation steps usefully. It was also possible to explain how scaling laws meant that something that is much larger than a human will have to move its limbs much more slowly to maintain efficient pendulum like movements. The quadrupedal models in their current form proved much too difficult to control effectively and further work is needed in this area.

Figure 2. The GaitSymKinect installation in the DinoZone marquee at the Cheltenham Science Festival 2015.

The exhibit could have considerable added value if combined with a 3D printer. The 3D models and software for this project are freely available to download (http://www.animalsimulation.org and Digital Object Identifier (DOI): 10.6084/m9.figshare.2008977) and are usable under the Creative Commons Creative Commons, Attribution licence (CC-BY) (http://www.creativecommons.org). The CAD models are watertight meshes suitable for 3D printing. The models are complete and producing a large 3D printed dinosaur would certainly be possible. However it is more practical to print out individual bones and this could be very useful for diverse educational needs such as anatomical instruction, or indeed as robust handleable items for partially sighted visitors. Complex bones such as the skulls are also decorative in their own right and could be used as visitor prizes. The files can be distributed to visitors and schools for printing on their own systems, and the unrestrictive nature of the license means that there is considerable opportunity for re-use and re-mixing. The single requirement is that their origin is acknowledged and particularly that their creation was funded by the NERC 50th Anniversary Summer of Science.

References

Auvinet E, Multon F, Aubin C-E, Meunier J, Raison M (2015). Detection of gait cycles in treadmill walking using a Kinect. *Gait and Posture* 41: 722-725.

Bates KT, Falkingham PL, Hodgetts D, Farlow JO, Breithaupt BH, O'Brien M, Matthews N, Sellers WI, Manning PL (2009). Digital imaging and public engagement in palaeontology. *Geology Today* 25: 95-100.

Bates KT, Manning PL, Margetts L, Sellers WI (2010). Sensitivity analysis in evolutionary robotic simulations of bipedal dinosaur running. *Journal of Vertebrate Paleontology* 30: 458-466.

Department for Business Innovation & Skills (2015). 2010 to 2015 government policy: Public understanding of science and engineering. GOV.UK.

Jensen E, Buckley N (2014). Why people attend science festivals: Interests, motivations and self-reported benefits of public engagement with research. *Public Understanding of Science* 23: 557-573.

Oikonomidis I, Kyriazis N, Argyros A (2011). Efficient model-based 3D tracking of hand articulations using Kinect. In *British Machine Vision Conference 2011* (Hoey J, McKenna S, Trucco E, eds.), pp 101.101-101.111. British Machine Vision Association.

Peters S, Hsu J Simple benchmarks for speed and accuracy of rigid body dynamic simulators. In *ECCOMAS Thematic Conference on Multibody Dynamics 2015, Barcelona, Spain, June 2015*.

Sellers WI (1996). A biomechanical investigation into the absence of leaping in the locomotor repertoire of the slender loris (*Loris tardigradus*). *Folia Primatologia* 67: 1–14.

Sellers WI, Cain GM, Wang W, Crompton RH (2005). Stride lengths, speed and energy costs in walking of *Australopithecus afarensis*: Using evolutionary robotics to predict locomotion of early human ancestors. *Journal of the Royal Society Interface* 5: 431-441.

Sellers WI, Hepworth-Bell J, Falkingham PL, Bates KT, Brassey CA, Egerton VM, Manning PL (2012). Minimum convex hull mass estimations of complete mounted skeletons. *Biology Letters* 8: 842-845.

Sellers WI, Manning PL (2007). Estimating dinosaur maximum running speeds using evolutionary robotics. *Proceedings of the Royal Society of London B* 274: 2711-2716.

Sellers WI, Manning PL, Lyson T, Stevens K, Margetts L (2009). Virtual palaeontology: Gait reconstruction of extinct vertebrates using high performance computing. *Palaeontologia Electronica* 12: 11A.

Sellers WI, Margetts L, Coria RA, Manning PL (2013). March of the titans: The locomotor capabilities of sauropod dinosaurs. *PLoS ONE* 8: e78733.

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