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Rigging and Re-posing a Human Model from Standing to Cycling Configuration

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Abstract. In this paper, we visualize and quantify the differences between two three-dimensional (3D) surfaces. A human participant was scanned in standing and cycling poses using a 3D scanner. We rigged the standing scan and re-posed them to a cycling pose. The two scans were then inspected for the differences in the various segments of the body. The objective of this paper is to demonstrate the potential of using a simple rigging method (Linear Blend Skinning) to re-pose a scan from one configuration to a pose of choice. This forms the first step of an innovative and accurate method to visualize human beings in any pose desired by a designer, engineer, or sports analyst. Applications of this method could be in the fields of fashion, ergonomics, and professional athlete services such as aerodynamic drag force analysis using computational fluid dynamics (CFD).

Keywords: Cycling · 3D · Rigging · Aerodynamics · Computational fluid dynamics · Modelling · Scanning

1 Introduction

The human body is challenging to define in all its entirety with numerous articulated joints. The definition of the articulating human body has evolved through the years, based on the application and the use. A well-known example among biomechanical engineers is the Hanavan Model [1] – in which the human shape is described as a collection of geometric shapes. Now, it has become crucial to describe the human shape to computers, where, for instance, product developers can use models to design their products. In the past, designers may have used a digital mannequin as shown in Fig. 1 for designing human-product interfaces. However, these are evidently approximated and the need for more realistic models is continual. There are models and anthropometric values available through empirical data [2], for instance, but the data cannot be applied to individuals for personalization. Some more directories of 3D human models [3] widely used in the fields of ergonomics, fashion, and military, incorporate only two racial groups. But it is well known that human shapes vary greatly based on the individual. These variations amplify when movement and soft tissue deformations are involved.

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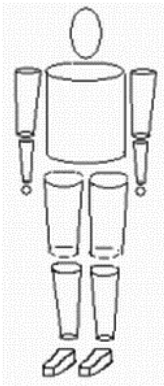

Fig. 1. An example of a human model that, while not incorrect, may be unsuitable for the product developer of today who might require a far more realistic version

Moreover, human models are generally only available in a limited number of poses – typically only standing and sitting [3]. While these poses may be standardized, they do not describe the spectrum of articulations that the human body is capable of. Designers could greatly benefit from the availability of models in a range of poses as human interaction with products occurs in a variety of configurations.

In addition, 3D modelling of human shapes has a special interest in sports communities such as cycling [4]. In road cycling, particularly, optimizing aerodynamic drag plays a significant role in performance. It is well-known that aerodynamic drag accounts for 70–90% of the resistance to a road cyclist [5]. The main factor in reduction of drag force is the frontal surface area of the cyclist.

Aerodynamic drag force is given by the formula in Eq. 1

$$F = C_d \cdot \rho \cdot v^2 \cdot A/2 \tag{1}$$

where F is Force,

C_d is the "drag coefficient", a dimensionless quantity that depends on shape and surface of the object,

ρ is the density of the air,

v is the relative velocity of object to the air,

A is the frontal surface area of the object.

As an example, "bike fitting" is a niche and growing sub-industry that analyzes the positions of cyclist on their bicycles – where the main recommendations are position corrections in order to offer the least frontal area to wind. In this regard, wind tunnels are the most reliable method to measure the aerodynamic forces on an object at variable speeds and yaw angles. Fans in a tunnel can be adjusted at a desirable speed but limited to a maximum speed (depending on the type and application of the tunnel) to generate wind. The object under study is mounted on a force-measuring platform which is equipped with sensors that record and output the forces experienced along one or more axes. Additionally, wind tunnels are used to visualize air flow by highlighting streaks of wind by means of smoke, laser, and so on.

Without testing inside a wind tunnel, using Eq. 1 to estimate force requires highly precise measurement of all the terms on the right-hand side. Hence, in recent years, various methods have been proposed to estimate drag force. Few researchers have used photographic data [6], and some commercial products can estimate the 'C_dA' (sometimes referred to as "drag area") term in the field by using portable pressure sensors in combination with other sensors [7]. A need for less simplistic approaches and higher accuracy led to studies performing computational fluid dynamics (CFD) analysis on 3D models (and body scans of athletes) [4]. CFD is a method to model and estimate forces on an object interacting with a fluid medium by decomposing the object into several smaller units or 'cells' and essentially cumulating the forces experienced by all these cells. The resulting sum gives an estimate of drag force using mathematical methods achieved by powerful computational tools.

In 3D modelling and animation of human shapes, 'rigging' refers to creating a skeleton for a 3D model for it to be manipulated into different shapes or poses [8]. In this contribution, we take the use case of road cycling and aerodynamics to demonstrate how CFD analysis can be performed on a rigged 3D shape.

2 Aim

The aim of this paper is to take a 3D scan of one person in a certain pose and re-pose them using a simple rigging technique to a cycling configuration. By performing CFD simulations on both the true and rigged version, the drag force and other parameters can be compared.

3 Methods

One participant (male, 28 years old, elite triathlete) was recruited for this study. Ethical approval was granted, and consent was taken from the participant. The participant was instructed to pose in two configurations: 1. a standing pose (Fig. 2), and 2. a cycling pose on a stationary indoor cycle.

Fig. 2. A 3D printed table-top statuette of the participant in the standing scan

The scanning was performed by trained researchers with a hand-held structured-light 3D scanner (*Artec Eva, Artec 3D, Luxembourg*). Each scan acquisition lasted approximately 3–4 min, during which the participant was required to be still and motionless, while the researchers circled him while holding the scanner. The participant may have made slight movements while breathing, minutely adjusting posture, etc.

The 3D scans were processed with software (*Artec Studio 11, Artec 3D, Luxembourg and Blender, Stichting Blender Foundation, Amsterdam, The Netherlands*) wherein they were ‘cleaned’, registered, and exported for the next phase.

The standing scan was manually rigged i.e., a basic set of bones (skeleton) was inserted inside the standing shape. Once the skeleton was in place, by visually comparing with the cycling scan, the shape was re-posed into a similar-looking cycling configuration. High sensitivity was not the requirement as the objective was to approximately mimic the pose.

For the CFD analysis, the ground truth scan as well as the re-posed scan were placed on a generic bicycle 3D model. Both objects (cyclist + bicycle) were approximately the same length and height: 1.53 m and 1.18 m, respectively. The files were converted to a CFD software-compatible mesh model (*Fusion 360, Autodesk Inc., USA*). The two meshed models were then subjected to a wind simulation of 11.6 m/s (40 km/h) using a CFD software (*FloEFD, Siemens AG, Germany*).

4 Results

The first visualization of the two scans – which we shall name ‘true’ and ‘rigged’ – is given in Fig. 3, where we juxtapose the 3D models. The models appear strikingly similar – a neutral facial expression accentuates this impression. In Fig. 4, the true and rigged versions are compared from a side view. Here, we see that there are dissimilarities around the neck, arm and feet segments.

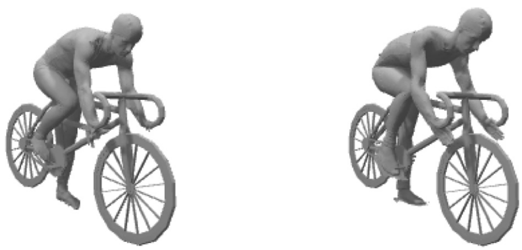

Fig. 3. Visualizing the differences in perspective. The left side is true, right side is rigged, the bicycle is generic and identical

In Table 1, we quantify the differences of the two shapes in the CAD environment. The rigged scan was larger in terms of surface area (by 2.37%), total volume (by 0.79%) and naturally suffered more drag (by 5.2%). These parameters were calculated by the *FloEFD* software. What is striking is in this table is that the differences are no greater than 5–6%.

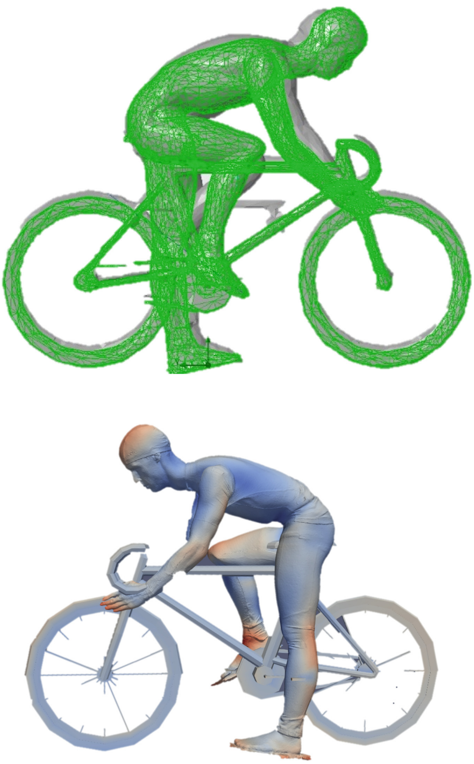

Fig. 4. (a) Visualizing the differences in side view overlapped. The green mesh is rigged, the grey is true. (b) Difference in surfaces highlighted by the intensity of the blue and red colors, mapped on to the surface of the rigged scan

Table 1. Comparison of the true and rigged versions.

	True scan	Rigged scan	Difference
Drag force at 40 km/h (N)	14.63	15.40	5.26 (%)
Total surface area (m^2)	2.29	2.37	3.49 (%)
Total volume (l)	55.50	55.94	0.79 (%)
Total cells in simulation (million)	13.42	13.36	−0.45 (%)

In Fig. 5, the pressure exerted on individual cells is indicated by the aid of a colored map on the true and rigged shapes. The differences in the shapes are also visible in this illustration, where the ‘intensity’ of the wind exerting force on the surface is evident.

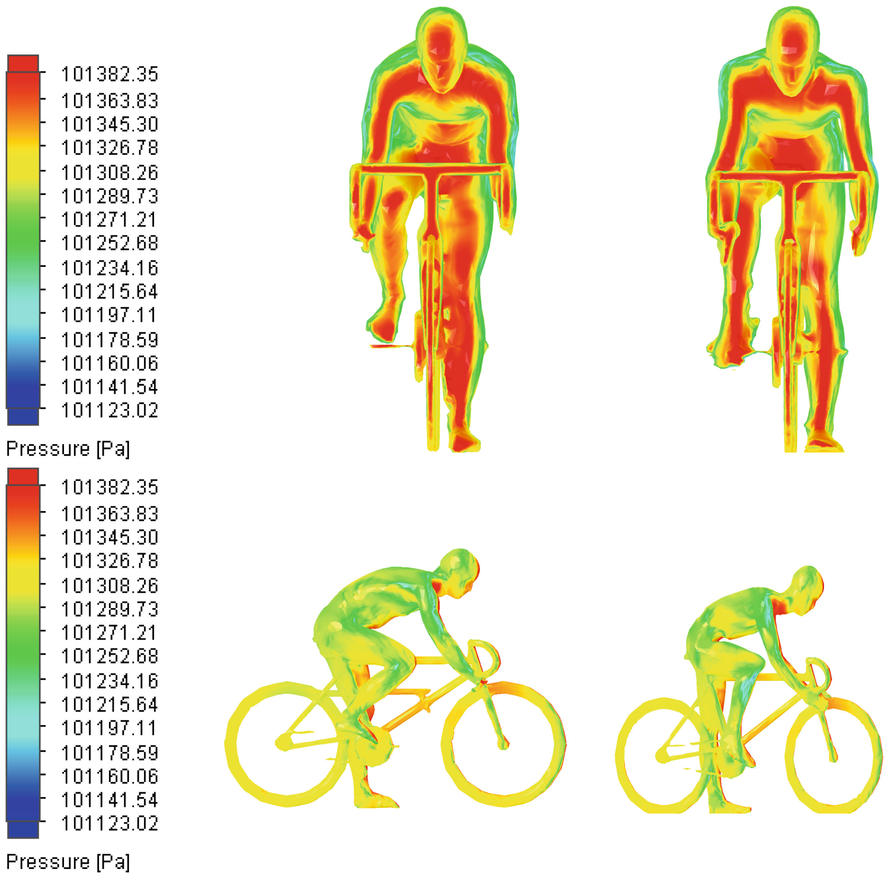

Fig. 5. Pressure maps in the front view (top) and side view (bottom). The force per unit area for each cell is calculated and color-coded based on the numeric value. The net pressure of all these cells (in the direction of wind) is the drag force. This figure illustrates that majority of the pressure from the air occurs in the front, the first surface that encounters oncoming air. The maps also confirm minute differences in the two shapes (see neck and left leg).

5 Discussion

The differences in the two models were generally within the range of acceptability for cyclists. The agreeability between the true and rigged scans is likely to increase as the shapes become more similar.

Skin and flesh are soft tissue material, which are easily deformed. When a person is standing, their surface area is different from when they are seated on a bicycle. The skin is stretched out in parts while on a bicycle – arms reaching out, knee joint extension, bending of the spine, and so on. However, in the rigging method employed by us, called Linear Blend Skinning (LBS), when we re-pose a standing scan to a cycling scan, the stretching around the joint regions is not realistic. In LBS, weights are attached to segments of the skin (or outline of the shape) surrounding the bones, signifying the extent to which the skin must move corresponding to the underlying bone. These weights do not reflect soft tissue deformations realistically. The drawbacks of this method can be seen in the flesh around the joints in the rigged version that are being extended/flexed/rotated close to their maximum range of motion. For example, one can notice this phenomenon around the hip and shoulders in Fig. 4.

The shortcomings of the method can be overcome by more careful manipulation e.g., by merely constructing a more elaborate skeleton within the shape and investing time in manual re-adjustment. At such a juncture, LBS becomes impractical because using visual inspection alone is not a feasible method when the objective is to perform the operations described in this paper at scale. It is time-intensive and highly subjective to the individual performing the rigging.

Hence, one of the next steps for our research is to devise a superior algorithm in terms of time consumed and accuracy. Perhaps employing joint angles as an input parameter will be an objective method for rigging a large number of human models.

For a highly sensitive application such as drag force analysis, a difference of 5% seems impressive at first glance. However, it has been reported that drag force derived from CFD analysis tends to be, to highly varying degrees, off the mark [9]. The accuracy depends on factors such as type of simulation, number of cells in the meshed model, and so on. Hence, another possible area of future research would be to investigate the differences between CFD drag values of a rigged model and drag values from a wind tunnel (the benchmark of drag force measurement).

6 Conclusion

The findings in this paper suggest that the method of linear blend skinning could be a suitable way to quantify cycling performance, but to perform this application at scale, an even less time-intensive algorithm needs to be formulated. To conclude if the values obtained are truly close to ground-truth, further measurements need to be made in a wind tunnel.

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