Performance Analysis of Virtual Human Bodies with Clothing and Hair from Images to Animation

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Abstract: Virtual human bodies, clothing, and hair are widely used in a number of scenarios such as 3D animated movies, gaming, and online fashion. Machine learning can be used to construct data-driven 3D human bodies, clothing, and hair. In this thesis, we provide a solution to 3D shape and pose estimation under the most challenging situation where only a single image is available and the image is captured in a natural environment with unknown camera calibration. We also demonstrate that a simplified 2D clothing model helps to increase the accuracy of 2D body shape estimation significantly.

Keywords: Clothing animation, Hair animation, SCAPE model, DRAPE model, PBS.

I. INTRODUCTION

In computer vision, a variety of human body models with different levels of specificity have been utilized to improve the performance of human action analysis, human motion capture, and body shape & pose estimation from images or videos. Machine learning can be used to construct data-driven 3D human bodies, clothing, and hair that,
1) Can be estimated from sensor data
2) Produce realistic animations
3) Low-dimensional enough to be computationally practical
4) May be applied to broader computer vision tasks or real-time applications.

In the entertainment industry, animators use computer graphics techniques to generate vivid 3D virtual characters and put them in virtual contents such as animated movies and games. Virtual bodies may also be used in medical applications where the body shape and weight of the patients can be tracked over time. In augmented reality, virtual people are overlayed on the real visual contents to provide new user experiences. Besides human body modeling, how to realistically represent clothing and hair is also on the top of the research agenda.

The research on human body shapes and clothing/hair modeling are closely related in a number of applications even though they have been largely treated as independent research topics in the vision and graphics communities. Human beings come in a variety of body shapes. Any virtual try on applications are meaningful when they have the real body shapes as input, which can be directly provided by users or estimated from various kinds of evidence. Body shape and pose estimation will be much more accurate when clothing is modeled because clothing obscures body shape. Unfortunately, the effect of clothing is ignored in most of recent work on body shape estimation. Online apparel shopping is another promising application, which involves clothing models that can adapt to different body shapes.

Real-time hair models are essential for gaming and accurate body height estimation in forensics. The standard techniques for clothing and hair modeling employ physics based simulation (PBS), which has the advantage of producing realistic results with typically high computational cost. Furthermore, the results are specific to a particular body model. Each character requires a new simulation with typically manual initialization.

Hair animation faces similar challenges, except that body pose/motion instead of intrinsic body shape plays a much more important role. These limitations make PBS suitable to animated movies that have an abundant time budget and a limited number of characters, but not for applications such as internet-scale virtual fashion or retail clothing try-on.

We explore clothing and hair models that have the following properties:
1) They should look realistic. They may not have the same level of realism as PBS, but they need to maintain fine details, such as the wrinkles and folding for clothing and plausible dynamics for both clothing and hair.
They should be low-dimensional for computational efficiency, which usually implies a parametric model such that the appearance is determined by a relatively small set of parameters.

They have the potential to be used in a broader range of applications. For instance, the clothing model should be generic so that it adapts to different body shapes. The hair model should allow real-time simulation for gaming, and preferably gives users interactive hair style control for virtual hair try on.

The human body is commonly modeled as a kinematic tree (similar to a puppet) rooted at the pelvis. Body parts such as limbs and the torso are connected through joints. The goal of pose estimation is to infer a set of relative joint rotations that determine the positioning of body limbs and parts in the images. Human Shape typically refers to intrinsic pose-independent shape such as height, weight, chest size, waist size and so on. A small set of coefficients for a parametric 3D body model is conveniently used to represent the human shape. We can obtain different human shapes by varying the coefficients.

II. CLOTHING ANIMATION

Clothing animation is important for all kinds of digital applications that involve dressed virtual characters. The traditional PBS methods for clothing animation have the following challenges.

Computation - They achieve realistic simulations at high computational cost, which is why they are often used in the off-line scenarios such as movie making. Note that, there exist hybrid methods that use PBS to simulate a low resolution mesh and use data-driven methods to learn the mapping between simulated coarse meshes and highly wrinkled detailed meshes from training set. These methods can achieve real-time performance, but their results are not comparable to pure PBS methods. Because of the complex nature of cloth dynamics, many applications (especially in games) rely on texture mapping on the body geometry or very coarse triangulated cloth meshes.

Simulation - In animated movies typically has very high quality because of the abundant computational resources. We focus on developing a datadriven clothing model that is realistic enough to present fine details and wrinkles, but is also efficient, low-dimensional, and can adapt to different body shapes. Given the estimated 3D body model regardless of its intrinsic shape, we are able to properly fit the estimated body with our clothing model. We envision such models to be appropriate for many other computer vision applications as well.

III. HAIR ANIMATION

Hair animation is a difficult task, primarily due to the large volume of hairs that need to be considered (a typical human head consists 100,000 hair strands). We avoid dealing with every single hair strand by building a low-dimensional model that

1) preserves the key dynamic properties of physical simulation at a fraction of the computational cost
2) allows user specifiable hair styles (length, softness) and external phenomena (wind). We envision this model to be used in real-time applications such as gaming.

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Physics based simulation for hair

Over 18,000 hairs are interpolated from a few hundred hair strand guides.

Fig. 1

IV. CHALLENGES

Body Shape and Pose Estimation from a Single Images. An image of a human body in a natural environment arises from the composite effect of numerous factors including lighting, occlusion, human pose and shape, camera view, clothing, and so forth. Body shape and pose estimation from images is very difficult mainly because there are so many
uncertainties that will affect what is perceived. We briefly review the challenges of body form estimation from a single image.

In this thesis, we provide a complete pipeline from getting the 3D body shape and pose from image evidence to animating the body with clothing and hair. This makes internet-scale customized clothing animation possible. We also show the potential of modeling clothing in computer vision tasks.

1. We describe a solution to the challenging problem of estimating human body shape from a single photograph or painting. Our approach computes shape and pose parameters of a parametric 3D human body model directly from multiple monocular image cues including silhouette, edges, and smooth shading. One of the key contributions is the formulation of parametric human shape from shading. We estimate the body pose, shape and reflectance as well as the scene lighting that produces a synthesized body that robustly matches the image evidence. To deal with ambiguity in a monocular image, we learn a low-dimensional linear model of human shape in which variations due to height are concentrated along a single dimension, enabling height-constrained estimation of body shape.

2. We propose a fully generative 2D eigen clothing model that is based on an underlying naked model with clothing deformation. This model significantly improves the inference of 2D body shape under clothing. Clothing deformation from the body is one-directional (clothing only makes the contour larger), therefore we model the skewed statistics of the eigen-clothing coefficients. This work is also the first to address the shape-based recognition of clothing categories on dressed humans. The preliminary work shows the potential of modeling clothing in computer vision applications.

3. We propose a 3D clothing model that is able to automatically dress synthetic bodies of any shape in any pose at run time. It provides a factored model of clothing shape so that pose-dependent wrinkles are modeled separately from body shape. Interpenetration is efficiently handled by solving a linear system of equations and this approach is significantly faster than physical simulation. The method is ideal for applications where the body shape is not known in advance such as retail clothing applications where users create different 3D bodies or estimate 3D body shapes. It is also useful for animating many bodies of different shapes because it removes the labor involved in either creating or finding the appropriately fitting garment.

4. We introduce a multi-linear reduced-space dynamical model for modeling hair. It is explicitly parameterized by a number of real-valued factors (e.g., hair length, hair softness, wind direction/strength, etc.) that make it easy to adjust the groom and motion of hair interactively at test time. We formulate our model using tensor algebra and illustrate how dynamics can be incorporated within this framework. Furthermore, we explicitly address the issue of hair-body collisions by a very efficient optimization procedure formulated directly in the reduced space and solved using a form of iterative least squares. Our formulation goes substantially beyond current reduced-space dynamical models.

Multi-linear dynamic hair model

Our multi-linear dynamic hair model allows real-time animation of 900 guides of hair with interactive control over the hair softness (red slider, the higher the softer) and length (blue slider, the higher the longer); bottom row shows interactive control of wind strength and direction

Fig. 2

V. CONCLUSION

We have presented a complete pipeline from estimating 3D human body shapes to animating the bodies with clothing and hair. Detailed 3D body shape estimation from images is a difficult problem. What is even more difficult is to estimate detailed 3D body shape from a single image. Even though we have shown that the reconstruction of a generic 3D object can be done using multiple silhouettes or photometric stereo images, those methods do not apply when image evidence is scarce. The philosophy behind our work is that as image cues become fewer, more human specific prior information needs to be used.
We use the SCAPE body model, but other realistic parametric models will also work. We show that smooth shading helps to refine the body shape estimation and our key contribution is the formulation of parametric body shape from shading. At the same time, we exhaustively explore the usage of other image cues such as silhouettes and edges. We do not claim that a single image is sufficient to estimate detailed body shape, instead we propose a solution to solve a problem which has been considered almost impossible. In order to make the smooth shading formulation work, we assume that the surface albedos and specularities are piece-wise constant. The assumption limits our method to be used in the cases where the person is close to naked or is wearing uniform colored clothing. With the advent of depth camera technologies, it is becoming increasingly popular to use a depth sensor in addition to a regular camera sensor. In the near future, we will see more applications with depth cameras.

The 2D eigen-clothing model is an attempt to deal with the clothing issue in body poses and shape estimation. Most work ignores the effect of clothing, which is fine if the model itself is coarse (e.g. simple rectangular body parts). However, there are many applications (e.g. surveillance) that require us to obtain a relatively detailed body shape estimation. We take the simple idea of modeling the clothing deformation as an additional layer of the body deformation and explore the statistical properties of the clothing deformation. The clothing model greatly improves the 2D body shape estimation from a single image.

After we estimate the 3D body shapes, we would like to automatically dress these bodies with perfect fitting clothing. This is very important for virtual fashion and online clothing retail. DRAPE is a complete solution for dressing people in a variety of shapes, poses, and clothing types. DRAPE is learned from standard 2D clothing designs simulated on 3D avatars with varying shape and pose. Once learned, DRAPE adapts to different body shapes and poses without the redesign of clothing patterns; this effectively creates infinitely-sized clothing. A key contribution is that the method is automatic. In particular, animators do not need to place the cloth pieces in appropriate positions to dress an avatar.

The DRAPE model simultaneously achieves automation, realism, and speed, which is unique among clothing simulation methods. By factoring the clothing shape and pose dependent deformations, we can train the DRAPE model with a reasonably small training set and later the clothing fitting can be done fully automatically. We have no intention to replace physics based simulation (PBS), because PBS produces the most realistic results. PBS is appropriate for animated movies without a doubt. We hope DRAPE model can open a whole new perspective and stimulate more research along the line of automation.

Finally, hair simulation is crucial for animated movies and gaming. The most important factor for hair simulation is speed. It is hard to develop a real-time hair simulator because the number of hairs on the real person is huge. Even if we use hair guides to represent a bunch of hairs, it is still computationally expensive. We believe that the movements of hairs are highly correlated, therefore we can represent hairs in a much lower dimensional space without sacrificing the simulated dynamics and realism of hairs. Our system could not be made real-time without modeling hairs in the reduced space. We believe that this is an interesting direction and would like to see more followup works in the near future.

VI. FUTURE WORK

There has been a lot of work on estimating human pose from images but human shape estimation is less explored. Detailed human shape estimation is limited by the realism of body model and the resolution of image observations. We have shown that we can achieve reliable estimation of human shapes by leveraging a data-driven detailed human body model. Because of the non-rigid nature of human body, the appearance of the body is affected by both articulated pose and shape. This inevitably leads to a high dimensional model and no known realistic body model can avoid this. Future work should focus on speeding up the optimization process of such high dimensional models. For an optimization in the high dimensional space, the quality of initialization is important. Therefore, a lot of work uses manual assistance to initialize the body model (including ours), which limits the usage of body shape estimation. We should pay attention to getting a good initialized pose automatically. The downside of using data-driven models for clothing animation is that they are not as realistic as PBS. In future work we will generate pose training data for different body shapes and learn a multi-linear or non-linear model that couples pose and shape. This will likely require significantly more training data and will trade computational efficiency for wrinkle detail. The pose training set may include bodies with different shapes so that we can get diversified wrinkle patterns. We may use multi-linear or non-linear methods to learn the pose deformation to preserve more high frequency wrinkles. Future work should also explore a wider range of garment and fabric types. We will also learn models of “tucked in” clothing and more complex garments with pleats, cuffs, collars, and closures (buttons and zippers).

Finally, clothing fit is not just about body shape but also involves individual preference. By training the model with different fit preferences (e.g. loose and tight) we should be able to add a “comfort” axis to the PCA shape basis that can be independently controlled. One challenge of hair simulation is how to use it in gaming. There are many things
going on in gaming including AI, physical contact, rendering, etc. Future research should focus on employing better techniques to parallelize the hair simulation. Low dimensional models of clothing and hair are very promising because they significantly reduce the computation. We envision more work in this direction in the next few years.

BIBLIOGRAPHY