WMG, IMC Building
University of Warwick
Coventry
CV4 7AL
United Kingdom

Alan Chalmers, Professor of Visualisation
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Report on PhD Thesis: Thomas Nindel

The PhD thesis of Thomas Nindel addresses the inverse rendering problem and in particular his research focusses on appearance matching and fabrication. In particular, the thesis sets out to make two major contributions to the field:

1. A novel inverse rendering method This contribution includes:
    a. An ability to automatically match the appearance of an authentic procedural wood model
    b. A loss function for coarse-structure matching based on signal phase in Gabor space
    c. A means for detecting tree-rings which can be used within dendrochronology
    d. A new approach to calculate derivatives of discontinuous procedural solid textures.
2. A new means for optimising the appearance of polyjet printing, including:
    a. An end-to-end differentiable pipeline
    b. A parameterisation of 3D print volumes based on material mixtures
    c. A metric for controlling the volume optimisation to favour desired visual stimuli.

The novel work was compared with state-of-the art techniques.

The thesis is divided into an Introduction, 3 chapters and a Conclusion and Future Challenges. It would have been perhaps more appropriate to have the short introduction be part of Chapter 1 and include these last two into a fourth chapter “4. Conclusions and Future Challenges”.

The **Introduction** specifies the challenges that the thesis addresses and then lists the contributions.

Chapter 1 is a comprehensive review of the background information that underpins the thesis. A detailed description of the mathematical foundations is provided. This is followed by a thorough description of the physics of light and in particular the transportation of light. The techniques used to model this light transportation and render the resultant images are also presented in detail. An important part of this chapter is the discussion about inverse rendering, how this can be considered as an optimisation problem (Section 1.8), and appearance models. The chapter concludes by considering in significant detail the anatomical and optical properties of wood, and colour 3D printing which is the focus of the rest of the thesis.

Chapter 2 presents the first contribution of the thesis, *appearance matching*. The focus of the contribution is to achieve an authentic appearance of wood using an anisotrophic material model within a rendered environment. The novel approach taken enables BSDF parameters to be automatically generated and also provides the ability to volume render thin wood veneers. An additional contribution is the connection of the work to dendrochronology and in particular the automatic identification of growth-ring boundaries. After the summary of the contribution, the first part of the chapter simply includes a paper on the topic that will shortly be submitted to a leading conference. The paper includes 4 authors. It would have been useful for the contribution of each author to the paper to have been identified. The results clearly show the success of the method for simulating the appearance of wood. The chapter concludes with a very brief description of differentiable rendering of procedural solid textures containing parametric discontinuities.

Chapter 3 provides the second contribution of the thesis, *appearance fabrication*. The novelty of this work is to optimise the material mixture space and apply the halftoning operation as the final step of

+44(0)2476 522012 alan.chalmers@warwick.ac.uk

the process. This enables the optimisation of visual stimuli including obtaining objects with spatial varying translucency. The research extends the 2017 work by Elek et al. from 2.5D to 3D. To avoid texture stretching artefacts the UV map is pre-processed to minimise any stretch. Margins are added to minimise colour bleeding and inpainting is also used to fill in any borders. The details are presented simply by including the paper that was published in ACM Transactions on Graphics in 2021. There are 5 authors of this paper, and as before, it would have been helpful to know what each one's contribution to the paper was. The results are impressive and clearly show how interior voxels in 3D printed resins can have a significant effect on the resultant object. The chapter concludes with a short discussion on how the textured mesh is processed into an appropriate data structure.

The one-page **Conclusion** summaries what has been achieved for appearance matching and fabrication, and highlights the different requirements of each, including the different start- and end-points and how sensitive each is to good initialisation.

Finally, the thesis concludes with a short **Future Challenges** description. This section highlights how the work has only focussed on diffuse surface reflectance and suggests that neural networks may offer some potential for extending this. This section also suggests that approaches that have been used for hair reflectance models may be used to enable appearance matching applications for other porous materials, such as foam or sponges.

Limitations
The abstract is too short to clearly be able to discern what the thesis is about. I also found simply inserting previously published/submitted papers in the thesis a little limiting. In particular, I would have liked to have seen some of the key results restated in the Conclusion and their importance fully re-emphasised.

Strengths
This thesis has presented a significant amount of research. The thesis clearly demonstrates that the candidate fully understands the field. This research has made an original contribution. There is certainly enough novel work here to qualify for PhD. The thesis is well written, and the candidate's contributions have already been published a top journal (ACM TOG) and I have no doubt the second paper will be accepted for a leading conference in the field shortly.

Questions for the PhD defence

There is one question that arises which would be helpful to have answered when the candidate defends his thesis.

1. Can you give more details as to why your system worked differently depending on the wood type?

Summary

In summary, this thesis is a important body of original work. The candidate has clearly shown a very good knowledge of the field and used this knowledge to make a significant contribution to appearance matching and fabrication. The candidate has clearly demonstrated the efficacy of his method on challenging applications.

The candidate's thesis is indeed fully worthy of the award of a PhD, the candidate should be particularly commended on the amount and quality of work undertaken, and therefore, I most strongly recommend the thesis for acceptance.

Yours sincerely

Professor Alan Chalmers

+44(0)2476 522012 alan.chalmers@warwick.ac.uk