RGC Ref. No.:
UGC/FDS11/E03/14
(please insert ref. above)

RESEARCH GRANTS COUNCIL
COMPETITIVE RESEARCH FUNDING SCHEMES FOR
THE LOCAL SELF-FINANCING DEGREE SECTOR

FACULTY DEVELOPMENT SCHEME (FDS)

Completion Report
(for completed projects only)

Submission Deadlines:
1. *Auditor's report with unspent balance, if any: within **six** months of the approved project completion date.*
2. *Completion report: within **12** months of the approved project completion date.*

Part A: The Project and Investigator(s)

1. Project Title

Web technologies for 3D content creation and collaborative manipulation

2. Investigator(s) And Academic Department(s) / Unit(s) Involved

Research Team	Name / Post	Unit / Department / Institution
Principal Investigator	Wai-Man PANG Adjunct Associate Professor	School of Computing and Information Sciences, Caritas Institute of Higher Education
Co-Investigator(s)	Jing QIN Associate Professor	Shenzhen University, Shenzhen, China
Others		

3. Project Duration

	Original	Revised	Date of RGC / Institution Approval *(must be quoted)*
Project Start Date	1 Oct 2014	--	
Project Completion Date	30 Sep 2017	--	
Duration *(in month)*	36 months	--	
Deadline for Submission of Completion Report		--	

Part B: The Final Report

5. Project Objectives

5.1 Objectives as per original application

1. Low-cost depth acquisition and mesh formation
We will develop software system to properly processing to point clouds captured from consumer level depth camera in different views. Although there are many similar solutions exist, our focus will be on the processing speed and web user friendliness, so that one can robustly reconstruct 3D objects easily.

2. Investigate and propose mesh denoising algorithms
Due the limitation of existing low cost depth camera, significant noise do exists in the captured point clouds and causing artifacts in the reconstructed 3D models accomplished in Task 1. We will analyze the nature of noise introduced in these depth cameras and propose sophisticated denoising approaches for mesh reconstruction. We will concentrate on denoising approaches which can process quickly, recover significant geometric features and preserve even weak/shallow features in the mesh.

3. Develop web-based collaborative mesh manipulation operations and related algorithms
We will improve many popular mesh processing methods including cutting, merging and simplification with better user interface, intuitive control of operation and performing collaboratively under web systems. Novel network architecture will be employed in order to facilitate simultaneous updates and modification of the same 3D content from different clients. Moreover, advanced manipulation operations will be proposed to allow mesh deformation, interactive painting, feature embedding and etc; in order to fulfill the needs of normal users in preparing DIY 3D contents.

4. Acceleration and optimization of the proposed algorithms under a distributed environment
We will tailor all our proposed algorithms to fit into a web environment, which is a distributed system with low end client machines. To improve interactivity and better resources utilization, further optimization of our proposed algorithms and acceleration with parallel computing devices like GPUs will be investigated and developed.

5. System integration and evaluation
The implemented novel algorithms will be deployed altogether in a software development kit (SDK) or as web services. A practical 3D web-based application will be developed based on the SDK in order to allow proper evaluation. One of the possible applications is a comprehensive platform for 3D printing object searching, sharing and customization on the web.

5.2 Revised objectives
Not applicable

5.3 Realisation of the objectives
(Maximum 1 page; please state how and to what extent the project objectives have been achieved; give reasons for under-achievements and outline attempts to overcome problems, if any)

All the objectives proposed are realized with the extent of each explained below:

1. **Low-cost depth acquisition and mesh formation**
   By employing low cost depth sensors, e.g. Kinect, the creation of 3D content from real objects can be realized by registration of point clouds and surface reconstruction of the whole scanned object. A prototype system is implemented and accompanies with a few web applications for C2C product trading.

2. **Investigate and propose mesh denoising algorithms**
   To reduce the significant noise introduced by low cost depth sensors during 3D scanning, mesh denoising algorithm is critical to ensure the quality of 3D mesh. Novel tensor-voting based method is thus proposed to retain geometric features and avoid introducing additional artifacts when removing noise. Extensive number of experiments are carried out to compare with many of the state-of-the-art methods which either fail to retain most of the original features presented in the object well, or cannot avoid additional artifacts.

3. **Develop web-based collaborative mesh manipulation operations and related algorithms**
   In addition to the development of some existing manipulation operations like scaling, clipping, hollowing on a collaborative platform. Novel approach to bas-relief embedding is proposed with the use of normal fields optimization. Our idea is to transfer the bas-relief modeling problem into a discrete space, and solve it in a least-squares manner, so that both structure and detail are well preserved.

4. **Acceleration and optimization of the proposed algorithms under a distributed environment**
   We found a significant hurdle in fast processing and rendering 3D contents in the distributed environment is the huge mesh data size. Thus, we proposed a novel compression scheme based on an optimization approach for the best vertex data permutation that minimizes compression error. All of these resulted in fast and high-quality vertex data decompression for real-time rendering.

   Furthermore, we have also proposed novel mesh feature descriptor which can greatly facilitate the content-based retrieval quality in 3D content cloud. Our proposed descriptor, namely spin contour, is less sensitivity to noise and sampling rate, furthermore, our novel spin-image-based local surface descriptor is fast and accurate in the mesh matching process.

5. **System integration and evaluation**
   To bring the proposed approaches into practice, we integrate the methods into suitable web applications, including C2C trading site, DIY 3D content cloud with collaborative functionalities. With these prototype systems and invited users, we carried out preliminary user studies to better understand the user satisfaction, as well as the effectiveness of the provided functionalities.

5.4 Summary of objectives addressed to date

Objectives *(as per 5.1/5.2 above)*	**Addressed** *(please tick)*	**Percentage Achieved** *(please estimate)*
1. Low-cost depth acquisition and mesh formation	✓	100%
2. Investigate and propose mesh denoising algorithms	✓	100%
3. Develop web-based collaborative mesh manipulation operations and related algorithms	✓	100%
4. Acceleration and optimization of the proposed algorithms under a distributed environment	✓	100%
5. System integration and evaluation	✓	100%

6. Research Outcome

6.1 Major findings and research outcome
(Maximum 1 page; please make reference to Part C where necessary)

We developed four key techniques which facilitate affordable 3D content creation and manipulation on distributed environment. First, a tensor-voting based mesh denoising technique [J1] to enable the use of low cost and quality depth sensor for a web-based C2C trading web [C1]. Unlike the existing mesh denoising techniques that focus on the first-order features or high-order differential properties, our approach exploits facet normals and quadric surfaces to recover a better piecewise smooth surface when reducing noise.

Next, we investigate a novel hardware-friendly compression approach for 3D vertex data [J4] to improve efficiency of data sharing and synchronization via network. Our approach uses optimization method to achieve a permutation of vertex information with best compression rate, and with exploitation existing graphics processing unit (GPUs).hardware texture compression circuits, our vertex data can be instantly decompressed within the hardware to enable fast rendering.

The third key technique relates to a popular 3D mesh manipulation, the bas-relief modeling [J3]. Our method tries to eliminate the artifacts introduced when using tone-mapping like approach to embedded shallow bas-relief on 3D mesh. By transferring the bas-relief modeling problem into a discrete space, then we can solve it in a closed form least-squares manner, and further achieve both structural and detail preservation.

Finally, in order to implement a useful and comprehensive web-based 3D content platform [C4,C5], we studied and developed search [C2] and recommendation [C3] capabilities of the system. We even developed our last novel key technique, called Spin contour [J2], which defined a better local feature descriptor for 3D mesh or point cloud. This descriptor is not an image but a 2-D point set. Comparisons show that the spin contour is robust to noise and sampling differences. The matching time is also improved over spin images.

With a well developed web-based 3D content prototyping platform [C4,C5], we can allow better sharing and trading of 3D print-ready objects on the Internet, as well as user-friendly customization of these 3D contents under the same platform. We believe this can attract more users to get involved the buying, tendering and DIY their own printable object on the web environment. A preliminary evaluation of the system shows that the quality of certain provided functions are satisfactory including the 3D content search and the collaborative customization tools.

6.2 Potential for further development of the research and the proposed course of action
(Maximum half a page)

This research project has proposed a number of enabling techniques for 3D contents, ranging from mesh processing, feature extraction, manipulation to even compression. A common direction for further development on all these techniques may include the use of machine learning approach. It is expected that weakness in our proposed feature descriptor can be compensated with deep learned features. It is a promising approach in view of the large amount of 3D mesh dataset available on the Internet. To generate denoised mesh from scanned point cloud or bas-relief modeling, the use of generative deep learning model (e.g. GAN) is worth a trial. However, further investigation on the convergence and quality of

produced denoising or bas-relief modeling capability are necessary. Finally, compression method based on the state-of-the-art graphics or deep learning hardware can be a challenging but interesting topic to be studied, as these novel hardware are becoming more popular and widely available, while we can better exploit their parallel processing abilities to improve the compression rate or decompression speed.

7. Layman's Summary

(Describe in layman's language the nature, significance and value of the research project, in no more than 200 words)

The research project concerns the development of low-cost solutions for normal web users to create 3D content in a DIY (Do It Yourself) manner. The ultimate goal is to tackle the difficulties related to the cost and quality of 3D model creation, modification and customization on the web environment, so as to promote the sharing, trading and utility of 3D contents. With the novel techniques developed in this project, normal user can make high quality meshes from affordable depth sensor, customizing their 3D content with fancy and quality bas-relief, sharing them efficiently via network with hardware-friendly compression, and finally enabling other users to query the 3D content via content-based method quickly.

With the integration of these functionalities into a single comprehensive cloud platform, we evaluated with invited subjects to ensure the proposed methods are useful and bring productivity and popularity of 3D content on web. A preliminary user study of the system demonstrated the quality of certain provided functions are satisfactory including the 3D content search and the collaborative customization tools. These evidence that the deliverables of the project have significant impact to our goal which tries to facilitate and promote handy and low-cost 3D content on the Internet.

Part C: Research Output

8. Peer-Reviewed Journal Publication(s) Arising Directly From This Research Project

(Please attach a copy of the publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.)

The Latest Status of Publications				Author(s) *(denote the correspond-ing author with an asterisk*)*	Title and Journal / Book *(with the volume, pages and other necessary publishing details specified)*	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this Report *(Yes or No)*	Acknowl-edged the Support of RGC *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*
Year of Publication	**Year of Acceptance** *(For paper accepted but not yet published)*	**Under Review**	**Under Preparation** *(optional)*						
2017				**[J1]** Mingqiang Wei*, Luming Liang, Wai-Man Pang, Jun Wang, Weishi Li, Huisi Wu	**Tensor Voting Guided Mesh Denoising, in IEEE Transactions on Automation Science and Engineering, vol. 14, no. 2, pp. 931-945,**		**Yes**	**Yes**	**No**
2016				**[J2]** Luming Liang ; Mingqiang Wei* ; Andrzej Szymczak ; Wai-Man Pang ; Meng Wang	**Spin Contour, in IEEE Transactions on Multimedia, vol. 18, no. 11, pp. 2282-2292,**		**Yes**	**Yes**	**No**
	2018			**[J3]** Mingqiang Wei*; Yang Tian ; Wai-Man Pang ; Charlie C.L. Wang ; Ming-Yong Pang ; Jun Wang ; Jing Qin ; Pheng-Ann Heng	**Bas-Relief Modeling from Normal Layers, in IEEE Transactions on Visualization and Computer Graphics.(Early Access)**		**Yes**	**Yes**	**No**
2018.				**[J4]** Kin Chung Kwan*, Xuemiao Xu, Liang Wan, Tien-Tsin Wong, and Wai-Man Pang	**Packing Vertex Data into Hardware-Decompressible Textures in IEEE Transactions on Visualization and Computer Graphics, vol. 24, no. 5, pp. 1705-1716**		**Yes**	**Yes**	**No**

9. Recognized International Conference(s) In Which Paper(s) Related To This Research Project Was / Were Delivered

(Please attach a copy of each conference abstract)

Month / Year / Place	Title	Conference Name	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this Report *(Yes or No)*	Acknowledged the Support of RGC *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*
[C1] Nov 2014 Hong Kong,China	Enabling 3D Online Shopping with Affordable Depth Scanned Models	International Conference on Smart Computing 2014 (SMARTCOMP 2014)		Yes	Yes	No

[C2] Dec 2014 Shenzhen, China	Enhancing Image Search Experience with Similarity-based Grouping	ACM Siggraph Asia 2014 (Poster Session)		Yes	Yes	No
[C3] Sep 2015 Osaka, Japan	Context-aware Scene Recommendation for Travel Photography	ACM Ubicomp 2015 (Poster Session)		Yes	Yes	No
[C4] Apr 2016 Taipei, Taiwan	A 3D Content Cloud: Sharing, Trading and Customizing 3D Print-Ready Objects	IEEE Second International Conference on Multimedia Big Data (BigMM) 2016		Yes	Yes	No
[C5] June, 2017 Copenhagen, Denmark	Collaborative 3D accessories customization and trading through web interface	3DTV Conference: The True Vision - Capture, Transmission and Display of 3D Video (3DTV-CON), 2017		Yes	Yes	No

10. Whether Research Experience And New Knowledge Has Been Transferred / Has Contributed To Teaching And Learning

(Please elaborate)

The research output are novel techniques to demonstrate how the new generation of 3D content creation and sharing platform can be better developed. These new knowledge are delivered in several 3D graphics or multimedia related courses within our school's digital entertainment degree programme to enrich student's exposure and knowledge.

11. Student(s) Trained

(Please attach a copy of the title page of the thesis)

Name	Degree Registered for	Date of Registration	Date of Thesis Submission / Graduation
nil			

12. Other Impact

(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, teaching enhancement, etc.)

nil

13. Public Access Of Completion Report

(Please specify the information, if any, that cannot be provided for public access and give the reasons.)

Information that Cannot Be Provided for Public Access	Reasons
nil	

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FACULTY DEVELOPMENT SCHEME (FDS)

Completion Report - Attachment
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RGC Ref. No.:	UGC/FDS11/E03/14
Principal Investigator:	Wai-Man PANG
Project Title:	Web technologies for 3D content creation and collaborative manipulation

Statistics on Research Outputs

	Peer-reviewed Journal Publications	Conference Papers	Scholarly Books, Monographs and Chapters	Patents Awarded	Other Research Outputs (Please specify)
No. of outputs arising directly from this research project [or conference]	4	5	0	0	--