出國報告（出國類別：研究）

赴新加坡出席第 2 屆數位影像處理國際研討會（ICDIP 2010）

服務機關：行政院飛航安全委員會
姓名職務：工程師／莊禮彰
派赴國家：新加坡
出國期間：民國 99 年 2 月 25 日至 2 月 28 日
報告日期：民國 99 年 4 月 20 日

目次

壹、目的及過程

1.1目的

本會於民國 98 年執行科發計畫「提升我國飛航事故調查能量計畫」，其中子計畫三「建立工程失效分析能量」係以有限元素分析（Finite Element Analysis, FEA）爲主體，整合國內現有能量，研發一套完整工程失效分析系統，建構未來飛航事故或重大運輸載具事故之調查能量。系統架構包含建構結構組件或破壞件之實體模型；導入 FEA 進行應力分析與驗證分析；進行材料之可靠度分析；透過材料測試結果研判破壞模式等，最後綜合各項證據與事實資料，以特效展示模組剖析工程失效之過程，並研判飛航事故之可能肇因。

「建立工程失效分析能量」之模型建構模組係建置乙套 3D 模型建構系統，重建結構組件或殘骸之曲面模型，並可輔助判斷結構組件破壞程度。本研究成果可大幅提昇飛安會工程失效分析之能量，亦應用於數起飛航事故調查中。

第 2 屆數位影像處理國際研討會(ICDIP 2010)訂於新加坡舉行，會議日期爲 2 月 26 日至 2 月 28 日，本會於 ICDIP 2010 大會發表工程失效分析之調查能量，論文名稱爲 Solid model reconstruction from triangular meshes（三角網格重建實體模型）。

1.2行程表

日　期		起 訖 地 點	任 務
月	日		
2	25	台北~新加坡	起程
2	26~27	新加坡	會議
2	28	新加坡~台北	返程

貳、數位影像處理國際研討會

2.1 ICDIP 概述

第 2 屆數位影像處理國際研討會（The 2nd International Conference on Digital Image Processing, ICDIP 2010）由新加坡計算機科學與訊息技術協會（International Association of Computer Science and Information, IACSIT）主辦，會議日期為 2 月 26 日至 2 月 28 日，會議目的為提供一個會議平台，讓世界各地之研究人員、工程師、學者以及專業人士等，分享彼此的數位影像處理研究成果。同時間 IACSIT 同時舉辦 7 個領域的研討會，除數位影像處理技術外，也包括電腦自動化工程、通訊網路、奈米光電、電力能源、工業物流、流體力學及熱學等技術領域。

新加坡計算機科學與訊息技術協會（IACSIT）為註冊的國際科學協會，總部位於新加坡，IACSIT 組織內有數十個專業委員會，並在世界各地設置辦事處，致力於計算機科學與訊息技術方面的交流，促進相關技術的研究發展。IACSIT 協會所主辦之學術年會、研討會及專題討論等，皆對該領域有深遠的影響及貢獻。職於 ICDIP 2010 大會發表 3D 模型建構系統之研究成果，進而瞭解國際未來研究發展方向及趨勢，與各國專家學者交換研究心得、吸取他人寶貴之研究經驗，並作為日後工程失效分析研究之參考。

2.2 ICDIP 議程表

今年 ICDIP 會議地點在新加坡之新達城（Suntec Singapore International Convention & Exhibition Centre），會議日期為 2 月 26 日至 2 月 28 日，詳細會議議程如圖 2.1， 參加人員為來自世界各國之專家學者、研究人員等，此研討會投稿論文皆以口頭方式報告，共計發表 86 篇論文，可在大會網站取得相關資訊（http://www.icdip.org/）。

2010 IACSIT SINGAPORE CONFERENCES

2010 IACSIT SINGAPORE CONFERENCES SCHEDULE

2010 The 2nd International Conference on Computer and Automation Engineering (ICCAE 2010)
2010 The 2nd International Conference on Digital Image Processing (ICDIP 2010)
2010 The 2nd International Conference on Communication Software and Networks (ICCSN 2010)
2010 International Conference on Nanotechnology, Optoelectronics and Photonics Technologies (NOPT 2010)
The 2010 International Conference on Electrical and Energy Systems (ICEES 2010)
2010 International Conference on Industrial and Logistics Technology (ICILT 2010)
2010 International Conference on Fluid Dynamics and Thermodynamics Technologies (FDTT 2010)

Suntec Singapore International Convention & Exhibition Centre

Singapore

Feb 26 - 28, 2010

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圖 2.1　2010 IACSIT 會議

ICDIP 2010

Afternoon, Feb 27, 2010 (Saturday)

Room 308 ICDIP

13:30 - 14:10	Plenary Speech 6 Prof. Charles M. Falco University of Arizona, USA

SESSION – ICDIP - 01
Session Chair:
Time: 14:15 – 15:30

P006	A new digital image watermarking using wavelet transform domain Hadi Pournader, Mohammad Firouzmand, Saeed Ayat
P007	Human Face Recognition by Euclidean Distance and Neural Network Chomtip Pornpanomchai, Chittrapol Inkuna
P010	Effect of Proportion on Stopping Hermann Grid HSiu Wen Wang, Shyh-Huei Hwang, C. F. lee
P017	Degraded Character Recognition Based on Gradient Pattern Ramesh Babu, Ravi Shankar, Manish Kumar
P018	A New Approach to Construct Generalized Local Voronoi Diagrams Via Digital Image Processing M. Ersin YUMER, Bilge KOCER, M. Bilgehan TOSUN
P020	Automated Radial Basis Function Neural Network based image classification system for diabetic retinopathy detection in retinal images ANITHA J, kezi selva vijila C, jude hemanth D
P021	Thai Handwritten Character Recognition by Euclidean Distance Chomtip Pornpanomchai, Pattara Panyasrivarom, Nuttakit Pisitviroj, Piyaphume Prutkraiwat
P023	Peak Load Demand Forecasting Using 2-Level Discrete Wavelet Decomposition and Neural Network Algorithm Pituk Bunnoon, Kusumal Chalermyanont, Chusak Limsakul
P026	Visual Hull Computation Based on Level Set Method XU Jian, WU XiaoJun, WEN Peizhi, SONG Peng
P027	Hybrid Particle Swarm Optimisation for Data Clustering Sing Loong Teng, Chee Seng Chan, Mei Kuan Lim, Weng Kin Lai
P030	Development of Neural Network Techniques for Finger-Vein Patterns Classification Jian-Da Wu, Chiung-Tsiung Liu, Yi-Jang Tsai, Jun-Ching Liu, Ya-Wen Chang
P033	A Hybrid Approach for Ellipse Detection in Real Images Dilip Prasad, Maylor K.H Leung
P034	Facial Image Recognition Using VQ Histogram in the DCT Domain Qiu Chen, Koji Kotani, Feifei Lee, Tadahiro Ohmi
P035	Fast and Efficient Search for MPEG-4 Video Using Adjacent Pixel Intensity Difference Quantization Histogram Feature Feifei Lee, Koji Kotani, Qiu Chen, Tadahiro Ohmi

P041	Spatial Wise Image Co-Clustering - A New Approach for Image Pair Segmentation Mariusz Paradowski
P042	Model-based Human Action Recognition Nattapon Noorit, Nikom Suvonvorn. Montri Karnchanadecha
P043	Feature Study And Analysis For Unseen Family Classification Mohammad Ghahramani, Hee Lin Wang, Wei Yun Yau, Eam Khwang Teoh
P047	Classification Fresh Aromatic Coconuts by using Polynomial Regression Suppachai Madue, Thanate Khaorapapong, Montri Karnjanadecha

15: 30 - 15: 40	Coffee Break

SESSION – ICDIP - 02
Session Chair:
Time: 15:40 – 18:30

P052	Application of DCT and Binary Matrix Technique for Color Medical Image Compression G Uma Vetri Selvi, R Nadarajan
P059	Generation Algorithm of Craniofacial Structure Contour in Cephalometric Images Tanmoy Mondal, Asish Jain, Harish Sardana
P060	Solid model reconstruction from triangular meshes Tien-Tung Chung, Li-Chang Chuang, Jhe-Wei Lee, Shun-hsiung Hsu
P062	Interior photon absorption based adaptive regularization improves diffuse optical tomography Samir Kumar Biswas, Kanhirodan Rajan, Ram Mohan Vasu
P064	Automatic Classification of Bacterial Cells in Digital Microscopic Images Parashuram Bannigidad, P.S. Hiremath
P065	Embedded System based driver drowsiness detection system Syed Zahidul Islam, Mohd Alauddin Mohd Ali, Razali Jidin
P069	MRF Based Joint Registration and Segmentation of Dynamic Renal MR Images Dwarikanath Mahapatra, Ying Sun
P075	Statistical Tools for Evaluating Classification Efficacy of Feature Extraction Techniques Debdoot Sheet, Vikram Venkatraghavan, Amit Suveer, Hrushikesh Garud, Jyotirmoy Chatterjee, Manjunatha Mahadevappa, Ajoy Ray
P078	A Multi-Cue Based Algorithm For Skin Detection Under Varying Illumination Conditions Fangwen Zhai, Zehong Yang, Yixu Song, Peifa Jia
P079	Hybrid Method for Hand Segmentation Chompoo Suppatoomsin
P084	Efficient ECG Signal Analysis using Wavelet Technique for Arrhythmia Detection: An ANFIS Approach Prabhakar Khandait, Narendra Bawane, Shyamkant Limaye
P093	Wavelet Transform based Medical Image Enhancement using Human Visual Characteristics Manoj Alwani, Dushyant Goyal
P096	Image Interpolation By Adaptive 2-D Autoregressive Modeling Vinit Jakhetiya, Ashok Kumar, Anil Kumar Tiwari
P099	Color Retinal Image Coding Based on Entropy-Constrained Vector Quantization Agung Wahyu Setiawan, Andriyan Bayu Suksmono, Tati Rajab Mengko

P115	Pixel Color Feature Enhancement for Road Signs Detection Qieshi Zhang, Sei-ichiro Kamata
P118	Gesture Recognition based on Neural Networks Jeong Dr
P124	Bayesian Level Set Method Based on Statistical Hypothesis Test and Estimation of Prior Probabilities for Image Segmentation Yao-Tien Chen
P128	Polymorphic robotic system controlled by an observing camera Bilge KOCER, Tugce YUKSEL, M. Ersin YUMER, C. Alper OZEN, Ulas YAMAN
P129	Extracted Facial Feature of Racial Closely Related Faces Chalothorn Liewchavalit, Masakazu Akiba, Tsuneo Kanno, Tomoharu Nagao
P132	A Suervey on Image Interpolation Methods ashok kumar, vinit jakhetiya, Anil kumar Tiwari
P136	A Self Teaching Image Processing and Voice Recognition based Intelligent and Interactive System to Educate Visually Impaired Children asim iqbal, Umar Farooq, hassan mahmood
P149	An Improved Algorithm for Restoration of the Image Motion Blur wenshuo gao, lei yang, weiwei zheng, xiaoyu wu
P305	Enhancements in Medicine by Integrating Content Based Image Retrieval in Computer-aided Diagnosis Preeti Aggarwal, H.K. Sardana
P306	Segmentation of image using texture gradient, marker and scan based watershed algorithm Roshni VS, Dr Raju G Kurup
P307	A Novel approach to Transformed Biometrics using successive projections E.S.GOPI
P318	Cell Quantification And Watershed Segmentation In Time Lapse Microscopy Dr.RM.Suresh, N.Jayalakshmi
P322	Asymmetric Locating Position of Information Hiding against Tampering Yulin WANG
P327	Color Image Segmentation – A review Dr. Mrs. Kanchan S. Deshmukh
P330	Pre-Processing for Noise Reduction in Depth Estimation Seong-O Shim, A. Malik, Tae-Sun Choi

Morning, Feb 28, 2010 (Sunday)

Room 320 ICDIP

SESSION – ICDIP -03

Session Chair:

Time: 8:45 – 10:20

P331	Comparative Wavelet, PLP and LPC Speech Recognition Techniques On the Hindi speech digits Database Mr A N MISHRA, Dr M C Shrotriya

P338	An approach for ordered dither using Artificial neural network CHATTERJEE Arpitam, TUDU Bipan, PAUL Kanai Chandra
P339	Iris Detection based on Pupil Prospect Point and Horizontal Projections Muhammad Shahid and Dr. Tabassam Nawaz
P340	Face Detection In Color Images Using Skin Color, Laplacian Of Gaussian And Euler Number Shylaja S S, K N Balasubramanya Murthy, S Natarajan, Ramya S, Radhika S, Nikita J and Prateek R
P341	Feature Selection for Facial Expression Recognition using Deformation Modeling RuchirSrivastava, TerenceSim, Shuicheng Yan, Surendra Ranganath
P346	Pattern Recognition Based on Multi-Agent CHENG Xian-Yi, ZHU Qian and WANG Lili
P352	Image Retrieval Using Feature Extraction Based On Shape And Texture T.Tharani and M.Sundaresan
P358	User Region Extraction from Dynamic Projected Background for Virtual Environment System UHM Taeyoung, PARK Hanhoon, LEE Moon-Hyun, PARK Jong-Il
P361	Face Recognition by Hopfield Neural Network and No-balance Binary Tree Support Vector Machine Ke WANG, Haitao JIA
P363	Region of Interest based Robust Watermarking Scheme for Adaptation in Small Displays V.Sapthagirivasan, Kishore Mohan K B, Vemula Krishna Manohar
P366	Glomeruli Extraction by Canny Operator with an Eigenvalue Feedback Strategy ZHANG Jun, HU Jinglu, ZHU Hong
P370	Effective phonocardiogram segmentation using Time statistics and nonlinear prediction S.rajeswari, m.peer mohammed malik, s.brindha, s. Aranganathan
P372	Document Image Database Indexing with Pictorial Dictionary Mohammad Akbari, Reza Azmi
P375	Classification of Cast Iron Based on Graphite Grain Morphology using Neural Network Approach Pattan Prakash C, V.D. Mytri, P.S. Hiremath
P378	Multi-Hop Path Tracing Of Mobile Robot With Multirange Image Ramakanta Choudhury, Chandrakanta Samal, Dr Umakanta Choudhury
P379	Research and Realization of signal simulation on virtual instrument ZHAO Qi, HE Wenting, GUAN Xiumei
P384	Application of photogrammetry technology to industrial inspection ZHANG De-hai, LIANG Jin, GUO Cheng

10：20 - 10：30	**Coffee Break**

SESSION – ICDIP - 04

Session Chair:

Time: 10:30 – 12:10

P386	Wavelet Based technique for Texture Classification Yogita K. Dubey, A.D.Belsare
P388	Image Processing Techniques Applied To The Detection Of Optic Disk-A Comparison

	V.Vijaya Kumari,
P390	Association Rule Based Tuberculosis Disease Diagnosis ASHA.T, S. NATARAJAN
P391	Feature Based Registration Of Thorax X-Ray Images For Lung Disease Diagnosis R. P. Nugroho, A. Handayani, T. L. R. Mengko
P392	A Fuzzy Expert System Design for Diagnosis of Cancer Milindkumar V. Sarode, Dr. Prashant Deshmukh
P397	Simultaneous Detectionof Randomly Arranged Multiple Barcodes UsingTime Division Multiplexing Technique Saad Md. Jaglul Haider; Md. Kafiul Islam
P406	Performance Evaluation of MLP and RBF Feed Forward Neural Network for the Recognition of Off-Line Handwritten Characters Rahul Rishi, Amit Choudhary, Ravinder Kajal, Vijay Dhaka, Savita Ahlawat, Mukta Rao
P410	Image enhancement by curvelet, ridgelet & wavelet transform Vinay Mishra & Sr.Lect. Pallavi Parlewar
P420	A new threshold based median filtering technique for Salt & Pepper Noise removal Geeta Hanji, M.V.Latte
P452	Effect Of Selected Attribute Filters On Watermarks Florence Tushabe and Michael. H. F. Wilkinson
P455	Biometric Image Enhancement using Decision Rule Based Image Fusion Techniques G Mary Amirtha Sagayee, Dr S Arumugam
P464	A Study of Interval-Valued Fuzzy Morphology based on the Minimum-Operator M. Nachtegae, P. Sussner, T. Melange, E.E. Kerre
P466	Three-Dimensional Modeling of Plants: A Review Zhi-yong Bai, Xin-yuan Huang
P467	Using Ontology for Domain Specific Information Retrieval H.L.Shashirekha, S.Murali, P.Nagabhushan
P468	Genetic Algorithm and Evolvable Hardware for Adaptive Filtration and Analysis using Texture, Color and Boundary Vandana.V, Soumya Raja
P471	Symmetry Based Fast Marching Method for Icosahedral Virus Segmentation Guihua shan, Jun Liu, Liang Ye, Xuebin Chi
P472	Satellite Image Compression Using Wavelet Alb. Joko Santoso, F. Soesianto, B. Yudi Dwiandiyanto
P476	Knowledge Base Image Classification Using P-Trees Dr. M.Seetha, Mr. G. Ravi
P480	Decoding of QOSTBC Concatenates RS Code Using Parallel Interference Cancellation Zhenghang Yan, Yilong Lu, Maode Ma, Yuhang Yang
P481	Color-SIFT model: A robust and an accurate shot boundary detection algorithm M Sharmila Kumari and B H Shekar
P400	Tolerance Extended with Kernel FCM for Effective Data Clustering SR. Kannan, A. Sathya, S Ramathilagam
P049	Supervised Colour Image Segmentation Using Granular Reflex Fuzzy Min-Max Neural Network

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圖 2.2　ICDIP 會議議程表

圖 2.3　　新達城 Suntec Singapore

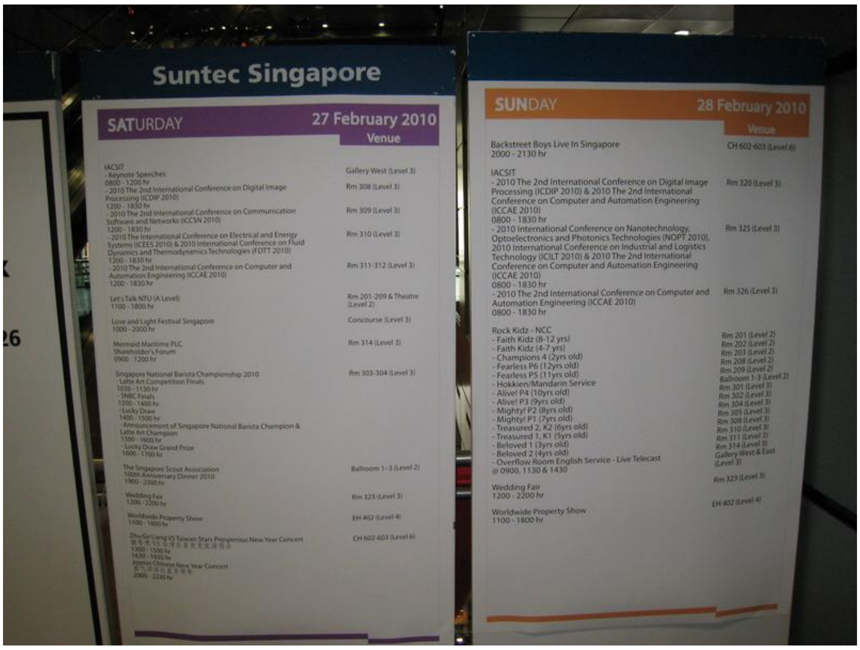

圖 2.4　　ICDIP 會議海報

圖 2.5　與共同作者合影（台大機械系鍾添東教授）

圖 2.6　ICDIP 會議場地

參、三角網格重建實體模型

3.1 研究緣起

一般工業產品之設計流程是先由構想開始，再經由電腦輔助設計（CAD）軟體繪製出構想之三維曲面模型，再以電腦輔助分析（CAE）軟體進行產品檢驗，如模擬結果達到產品設計要求，即可將此模型產品化，此種產品開發工程稱之爲「順向工程」；但相對於「逆向工程」而言，則是針對現有之模型或樣品，利用 3D 光學掃描裝備進行掃描，再將擷取之原型資料進行三維模型的建構與修改，並轉換至電腦輔助製造系統生產製造而產生最終產品。

本研究試圖將逆向工程技術應用於破壞檢驗以及事故殘骸重建等，旨在於建構出結構件及破壞件之三維模型，藉由 CAE 軟體進行應力分析；與過去實體實景重建相比，可有效地節省金錢、人力以及時間等方面等支出。

3.2 研究目的

飛機曲面模型資料係爲飛機公司之商業機密及智慧財產權，飛安會無相關設計圖檔；若發生大型飛航事故時，飛安會會向飛機公司提出結構分析之需求，並與飛機製造國之調查機構、飛機公司共同進行結構應力分析，但也無法獲得飛機原始設計模型。本模組係利用 3D 光學掃描儀器量測結構組件或殘骸的輪廓，將點資料自動轉換爲三角網格，加以編輯修改後，建構成 CAD 曲面模型，並導入有限元素分析 FEA 進行應力分析。以中小型飛航事故爲例，破壞之結構組件可能發生大變形、斷裂，甚至殘缺不全的情形，若能建構出破壞件的曲面模型，與未破壞結構組件之曲面模型作比對分析，可輔助判斷破壞件之破壞程度。此外該曲面模型也能結合多媒體編輯，展示結構組件破壞與形變等過程，此乃模型建構模組之研究目的。

3.3 光學掃描系統

於逆向工程技術中，如何量測物體的三維輪廓資料是極重要的課題；而量測儀器種類繁多，如何選定適當儀器以利於掃描工作的進行，是極爲重要之環節。一般而言，以量測探頭來區分可分爲接觸式及非接觸式；非接觸式又有干涉法、聚焦檢測及三角量測法，其中三角量測法又可分爲雷射及白光。

本研究使用 ATOS I 2M 掃描系統，爲德國 Optical Measuring Techniques Inc. (GOM)所製造之非接觸式光學掃描系統，如圖 3.1 所示，由光柵投影裝置及兩個工業級 CCD 所組成，其工作原理就如同人類的一雙眼睛，將光柵投影在待測件表面上，輔以光柵粗細變化及相位位移，並配合兩個 CCD 將所擷取的數位影像加以電腦運算處理，即可得到待測件的高密度點雲資料，經後續的計算與疊合，得到三角網格資料。

圖 3.1　ATOS I 2M 掃描系統

3.4 案例研究

某航空公司班機於某機場落地後，靠空橋旅客下機時，客艙地板發生冒煙情形，客艙組員請其餘旅客儘速下機，由地面機務人員關閉輔助發電機電源後滅火，所幸機載人員均安。初步調查之事實資料顯示冒煙係後貨艙輔助發電機電纜線支架斷落，電纜線與鄰近螺栓長期摩擦，以致絕緣外皮破損產生電線短路，產生之火花引燃下方隔熱毯造成貨艙與客艙通風口之煙霧。

爲建構電纜線支架之 CAD 曲面模型，本研究沿用逆向工程的概念，利用 3D 光學掃描儀器（ATOS）量測備品及受損支架之幾何輪廓，透過逆向工程軟體將高密度點資料自動轉換爲三角網格，加以編輯修改後，建構成曲面模型；將備品及受損支架之模型疊合，可以輔助研判受損支架之變形情形、斷裂位置及破壞程度。此外，建構完成之 CAD 曲面模型，可作爲有限元素分析的依據。

圖 3.2　電纜線支架

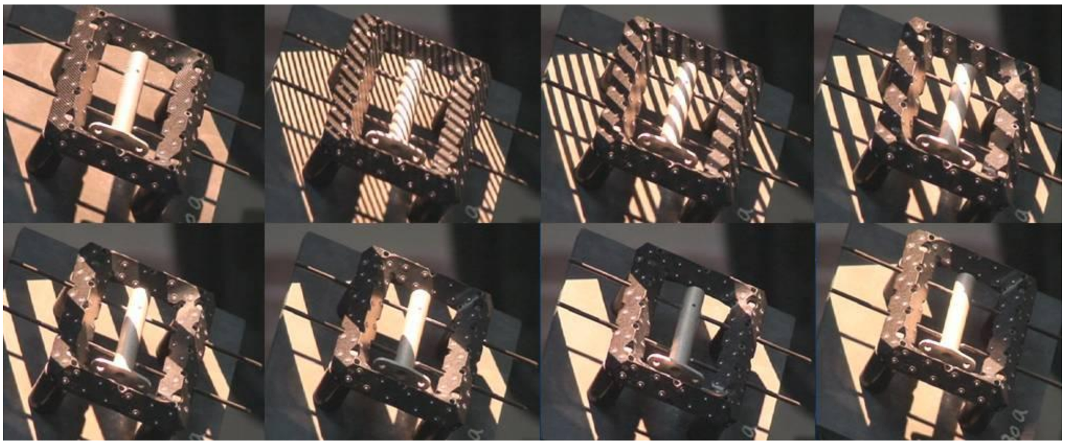

圖 3.3　掃描系統之光柵投影

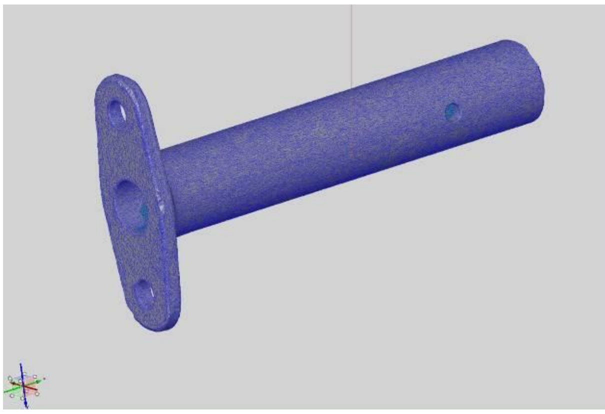

圖 3.4　　電纜線支架三角網格

3.5 研究方法

本研究「三角網格重建實體模型」之研究架構包括：資料重整、資料平滑化、資料分割、曲線擬合、曲面擬合、特徵擷取及模型輸出，如圖 3.5 所示，詳細資料詳附件 1。

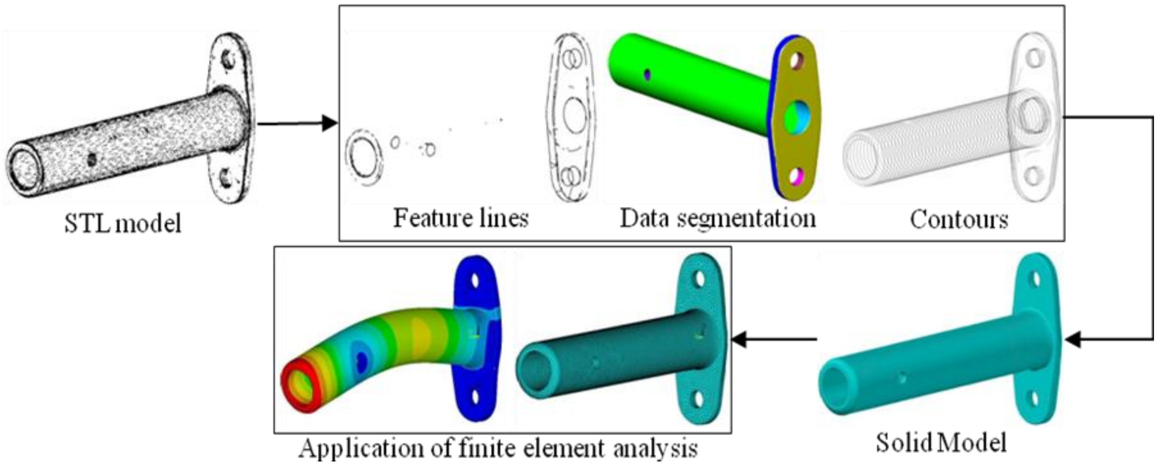

圖 3.5　　研究方法與架構

<u>特徵擷取</u>

實體模型是由平行切割輪廓重建而來。如果輪廓密度（相鄰切割輪廓的距離）太低，模型的特徵可能會遺失；如果輪廓密度太高，對於軟體處理來說輪廓的檔案可能過大且多餘。為了解決此問題，特徵擷取被用來改善使用合適輪廓密度重

建的實體模型之品質，特徵的資訊包括銳綠、脊線等，特徵擷取包括重要邊緣偵測、面片建立和細化。

<u>資料分割和曲面擬合</u>

STL 模型的平行切割輪廓重建實體模型，首先需決定切割平面，其步驟如下：

1. 藉由網格分割法將 STL 模型分割爲不同的區域。
2. 選取一個包含大量三角面片的平坦區域用來做爲切割平面。
3. 將被選取的區域擬合成一平面，並用以做爲參考切割面。

<u>平行切割輪廓</u>

擷取 STL 模型的平行切割輪廓共需要三個步驟。第一步是擷取在平行切層上的線段；第二步是減少在輪廓上的點數；最後一步則是用減少的輪廓點來重建 NURBS 曲線。因爲在模型上每一部分的尺寸都是不同的，所需的輪廓密度（相鄰切割輪廓的距離）也不相同，應用網格重新分配的結果於此，並用以決定區域邊界和各部分輪廓的範圍。

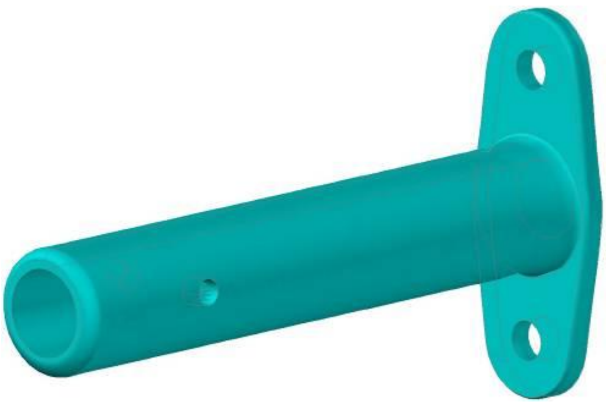

圖 3.6　實體模型重建結果

3.6 結論

本會於 98 年執行「提升我國飛航事故調查能量計畫」時，本計畫「建立工程失效分析能量」建置 3D 模型建構系統，重建結構組件或殘骸之曲面模型，輔助判斷結構組件破壞程度。本研究成果大幅提昇飛安會工程失效分析之能量，亦應用於數起飛航事故調查中。

肆、心得

針對本次科發計畫「工程失效分析整合與應用」，赴新加坡出席第 2 屆數位影像處理國際研討會（ICDIP 2010），一切圓滿且收穫豐富。職整理本次心得如下：

一、 國際研討會往往反應目前該項技術領域發展的最新趨勢，藉由參與國際研討會，世界各地研究人員齊聚一堂、彼此交換研究成果和心得，瞭解國際未來研究發展方向及趨勢。此次於 ICDIP 2010 大會發表研究成果，與各國專家學者交換研究心得，吸取他人寶貴之研究經驗，並作爲日後研究之參考。

二、 飛機模型係爲飛機公司之商業機密及智慧財產權，本會無相關設計圖檔；本研究以 3D 掃描儀器 ATOS 擷取實物外形並輸入電腦轉換爲 STL 模型，經案例驗證後，本研究成果可用於飛航事故調查工程失效分析之實體模型重建。

三、 ICDIP 2010 論文集已收錄於 Ei Compendex 和 ISTP。

伍、建議

一、 持續派員參與模型建構相關技術之國際研討會。

二、 持續發展逆向工程相關能量，建立工程失效分析及失效順序探討，以提升我國飛航事故調查能量。

Solid model reconstruction from triangular meshes

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ABSTRACT

This paper presents an approach to reconstruct solid models from triangular meshes of STL files. First, suitable slicing planes should be selected for extracting parallel intersection contours, which will be used for solid model reconstruction. Usually, a suitable flat region of triangular meshes of the STL model is selected as the bottom surface, and it can be fitted into a plane from the selected flat region. The flat region is separated by a mesh segmentation method, which uses a specified small threshold dihedral angle to divide all triangular facets into separated regions. Next, a series of parallel slicing contours are obtained by cutting the STL model through specified parallel cutting planes. Slicing contours are originally composed of a lot of line segments, which should be simplified and refitted into 2D NURBS curves for data reduction and contour smoothing. The number of points on each slicing contour is reduced by comparing the variation of included angles of each two adjacent line segments. Reduced points of each slicing contour are fitted into a NURBS curve in commercial CAD software. Finally, with a series of parallel 2D NURBS curves, the solid model of the STL facets is established by loft operations supplied in almost all popular CAD software. The established solid model can be used for other post processing such as finite element mesh generation.

Keywords: Solid model reconstruction, STL facet, data segmentation, surface fitting, NURBS curve

1. INTRODUCTION

For the requirement of fast production development, reverse engineering applications of objects has received significant attention from both research and industrial communities. Reverse engineering concerns with the process of generating a computerized representation of an existing object[1]. In reverse engineering process, clay models of objects are scanned into the computer by 3D scanners as stereolithography (STL) model composed of triangular facets. Usually triangular facets are considered as digital geometric entities referred to the data that describe the freeform shape of objects. However, surface modeling of objects is still needed in the reverse engineering process. It takes a significant amount of time and skill to reconstruct accurate surface models from the triangular facets. Solid model reconstruction is also required for post processing work such as establishing finite element meshes. For reconstruction purpose, NURBS curves and surfaces are two important representations of freeform model. There have been a lot of researches on various issues of surface model or solid model reconstruction using different algorithms such as parameterization, segmentation, and simplification[2]. These steps of solid model reconstruction are usually not automated and involved lots of manual operations by skilled designers inside commercial CAD software packages such as AutoCAD, Solidworks, Catia, …, etc.

In data segmentation research, Dong Hwan Kim et al.[3] presented algorithms by using iterative merging of adjacent triangle pairs based on the orientation of triangles for segmentation of 3D triangular mesh data. Ariel Shamir[5] formulates the segmentation problem as an optimization problem. Márta Szilvási-Nagy et al.[6] presented an algorithm which estimates face-based curvatures on triangle meshes. In feature extraction research, Andreas Hubeli and Markus Gross[7] used different feature extraction methods and compared their results. The methods include second order difference, extended second order difference, and best fit of polynomials. Sheng-Han Hsu and Jiing-Yih Lai[8] presented an algorithm for extracting geodesic or feature lines on triangular meshes.

Dong Go Jang et al.[9] proposed an approach for offset surface construction using 3D distance volumes which is created from converting an original compound surface into a triangular mesh. Sun Yuwen et al.[1] presented a direct extracting method to find sectional contours from point clouds. They create a base surface by skinning primary boundary curves and interior sectional curves. Jeffrey Marker et al.[10] presented a volumetric approach to reconstructing a smooth surface from a sparse set of parallel binary contours. Wang Qiang et al.[11] used a radial basis function interpolation method to render the surface of human organs by using data set containing parallel slicing contours. Houtmann Y. et al.[12] presented the use of critical points for adaptive local slicing in rapid prototyping.

In this paper, a computational pipeline has been developed to produce solid models from a set of parallel intersection

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contours. Section 2 describes the segmentation of the triangular meshes, and the slicing plane can be decided by fitting a plane to a selected flat region. In section 3, algorithms for contour construction are presented. In section 4, the solid models of two examples, a cable support and an angle plate, are reconstructed from the slicing contours by loft operations offered by most CAD software. Finally, section 5 includes some concluding remarks.

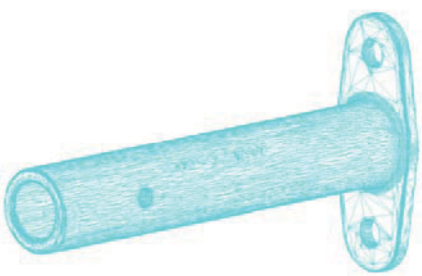
2. DATA SEGMENTATION AND SURFACE FITTING

In this paper, a solid model is reconstructed from parallel slicing contours of a STL model. The slicing plane should be decided first. This procedure is performed as following:

- A STL model is partitioned into separated regions by mesh segmentation method.
- A flat region, which contains many triangular facets, is selected to be used as the slicing plane.
- The selected region is fitted into a plane, which is used as the reference slicing plane.

2.1 Triangular mesh segmentation

The STL file contains the coordinates of a normal vector and three vertices of each facet, and AutoCAD software is used to display the triangular facets of a STL file, as shown in figure 1. Mesh data can be segmented with various criteria according to segmentation purposes, and there are also many attributes affecting segmentation result, such as linear planar characteristics, dihedral angles, and curvature based etc. In this paper, mesh segmentation is based on the dihedral angle between two normals of two adjacent facets. The proposed mesh segmentation contains two phases. In phase I, the STL model is roughly partitioned into many regions. Then, facets in small regions will be merged into large regions in phase II.


(b) Hidden-line display


(c) Gouraud shaded display

Figure 1. Triangular mesh model of a cable support

- **Mesh segmentation**

Figure 2 shows the algorithm of phase I. The STL model is divided into several regions having similar geometric properties based on a given small dihedral angle of two adjacent facets:

$$ang(\vec{n}_i, \vec{n}_j) \le \delta \quad (1)$$

where $\vec{n}_i$ and $\vec{n}_j$ are unit normals of two facets respectively, *ang()* is the dihedral angle of two facets. δ is the threshold value. Adjacent facets are merged into same region when Eq(1) is satisfied[3]. Phase I result of the cable support is shown in figure 3. The value of threshold angle is set to the value of about 7.2 degrees, which is decided by many tests. In AutoCAD, the needed reference facet can be selected directly, and the region containing the selected facet is extracted as shown in figure 4. The flat region is fitted into a plane, and it is considered as the reference slicing plane of the STL model.

- **Mesh redistribution of small regions**

After the mesh segmentation, there exist many small regions with few facets, and these small regions are usually transition boundaries between two large regions. This step redistributes facets in small regions into nearby larger regions. We defined a threshold facet number (n_F) to identify small regions. For the cable support example, regions with facet number less than n_F =100 is considered as small regions.

The operation of facet redistribution starts at the boundary facet of the small region, which is connected directly to the nearby large regions, as shown in figure 5. The algorithm of mesh redistribution is shown in figure 6. Mesh redistribution result for the cable support is shown in figure 7. The enlarged views in figure 3 and 7 demonstrate that the segmentation result is improved.

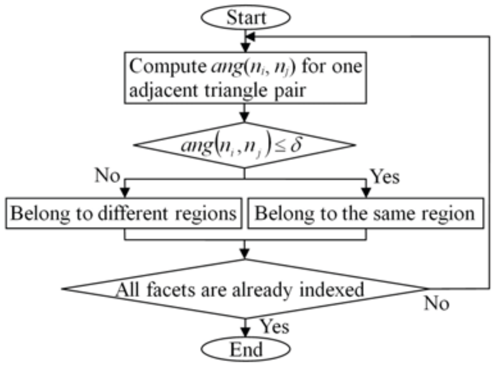


Figure 2. Procedure of mesh segmentation

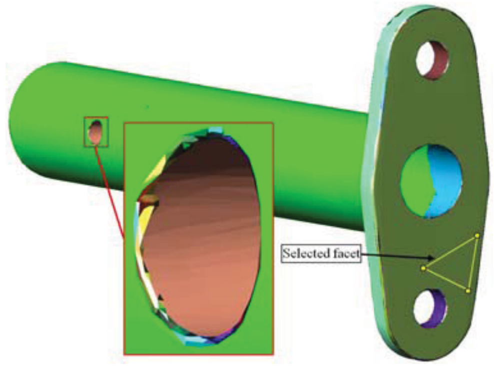


Figure 3. Result of mesh segmentation

Figure 4. Extracted region

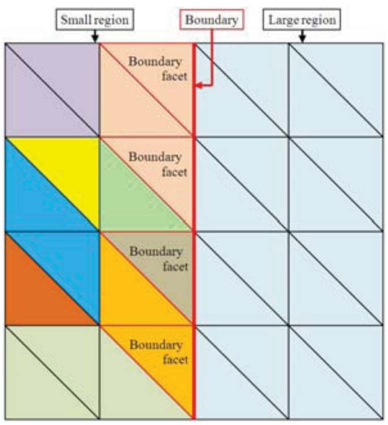


Figure 5. Schematic of small boundary region facets

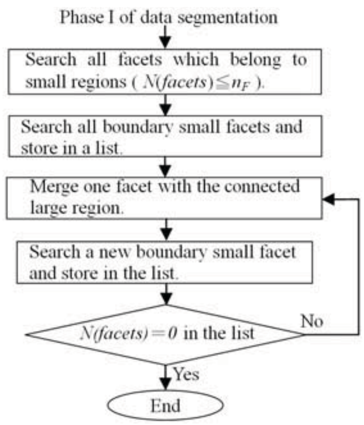


Figure 6. Procedure of mesh redistribution

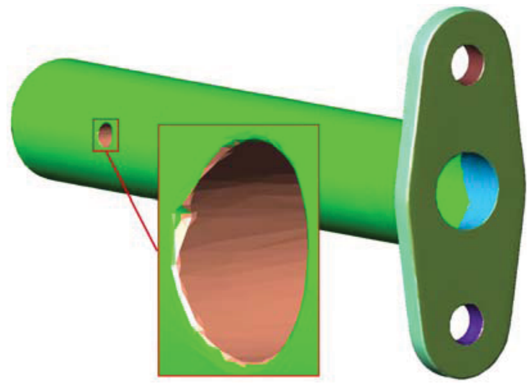


Figure 7. Result of mesh redistribution

2.2 Surface fitting of the selected region

The normal direction of slicing plane should be aligned with a selected direction. Hence, a reference facet in a flat region should be selected. The model is partitioned to many regions whose facets have similar geometric properties in phase I of data segmentation, and the region containing the selected facet is extracted. All facets on the selected region are fitted into a plane by the surface fitting method. The least square error method is used to fit the plane, and the equation of the plane is defined as:

$$z = ax + by + c \tag{2}$$

where a, b and c are constants. In order to solve these constants, the least square error method results in the matrix as following[13]:

$$\begin{bmatrix} \sum_{i=1}^{m} x_i^2 & \sum_{i=1}^{m} x_i y_i & \sum_{i=1}^{m} x_i \\ \sum_{i=1}^{m} x_i y_i & \sum_{i=1}^{m} y_i^2 & \sum_{i=1}^{m} y_i \\ \sum_{i=1}^{m} x_i & \sum_{i=1}^{m} y_i & \sum_{i=1}^{m} 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{m} x_i z_i \\ \sum_{i=1}^{m} y_i z_i \\ \sum_{i=1}^{m} z_i \end{bmatrix} \tag{3}$$

where m is the number of total points on the region. The constants a, b and c can be solved from Eq(3). Because the facets near the boundary edges affect largely the normal direction of the fitted plane, the normal direction is better decided from regions in phase I.

3. PARALLEL SLICING CONTOURS

After accomplishing the pre-processing, the major steps of the approach can be carried out. Three steps are required in extracting parallel slicing contours of the STL model. The first step is to extract the segmented lines on the parallel slices, the second step is to extract the reduced points, and the final step is to reconstruct the NURBS curves with the reduced contour points. Because the dimension of each part is different in a model, the needed contour density (distance between adjacent slicing contours) is also different. The result of mesh redistribution is applied here to decide region boundaries and ranges of the contours for each part.

Mesh redistribution can refine the boundaries of connected parts, and it is easier to determine different contour densities for each part. For the cable support example, the bottom base is thinner than the body tube, and the bottom base needs higher contour density than the body tube, as shown in figure 8.

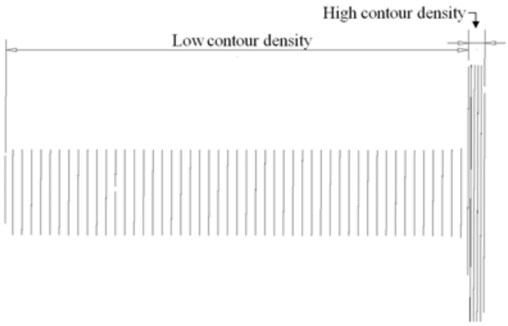


Figure 8. Different contour densities for two parts

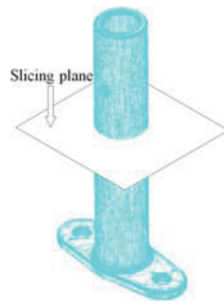


Figure 9. Slice cutting through the STL model

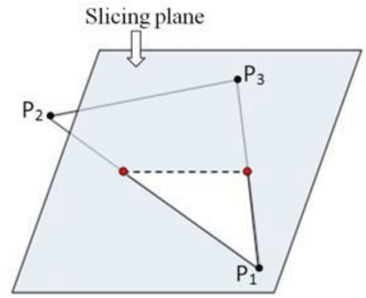


Figure 10. Two intersection points on the slicing

3.1 Extracting the segmented contour lines

When one plane cuts through the model, there are lots of triangular meshes intersecting the plane as shown in Figure 9. Figure 10 shows the line segment obtained from the intersection of the cutting plane and the STL facet. It is obvious that, for critical plane position, the intersection may be only one point. The three vertices of one facet are known, so the line equation of each facet edge can be expressed easily as:

$$P = P_i + t\left(P_j - P_i\right) \tag{4}$$

where P_i and P_j are any two vertices of the facet, and the coordinates are (x_i, y_i, z_i) and (x_j, y_j, z_j) respectively. The plane equation of the slicing plane is represented as:

$$ax + by + cz + d = 0 \tag{5}$$

where a, b, c, and d are constants. By solving the simultaneous equation of the line and the plane equation, the variable t can be solved as:

$$t = \frac{ax_i + by_i + cz_i + d}{a\left(x_i - x_j\right) + b\left(y_i - y_j\right) + c\left(z_i - z_j\right)} \tag{6}$$

The coordinates of the intersection point P can be derived by replacing t in Eq(4). After getting all intersection points, the contour points of the cross-section are constructed with lots of segmented lines. In order to reconstruct the solid model, the contours of the cross-sections are used. It is important to decide that how many contours are needed for the model. In general, the reconstructed model is better with more contours. The ideal situation of reconstruction is with infinite number of contours. Generally, for more complicated model, more contours are needed. Figure 11 shows the model with 55 parallel contours.

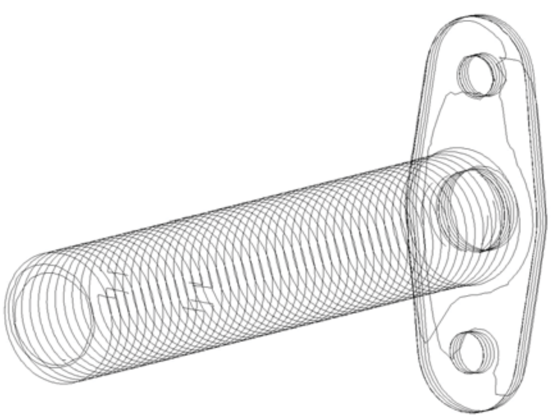


Figure 11. Model with 55 contours

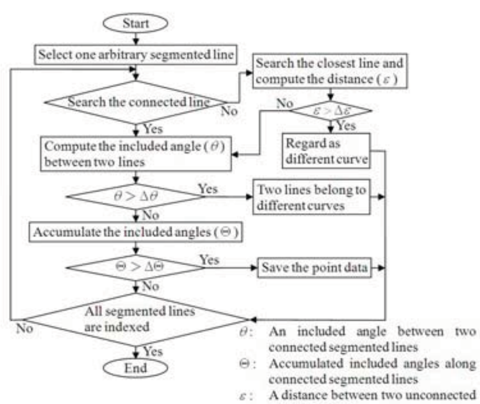


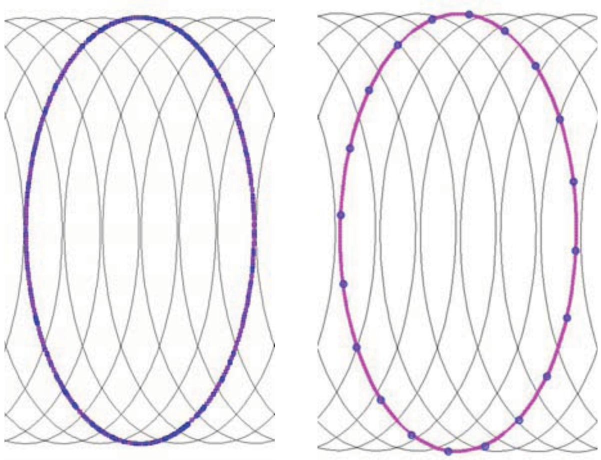
Figure 12. Procedure of extracting reduced contour points

3.2 Points reduction and NURBS contour reconstruction

In section 3.1, the contours are composed of segmented lines. If the number of points on a contour is large, the the contour shape will be smooth. However, it will affect the efficiency of the software processing for contours with large number of points.

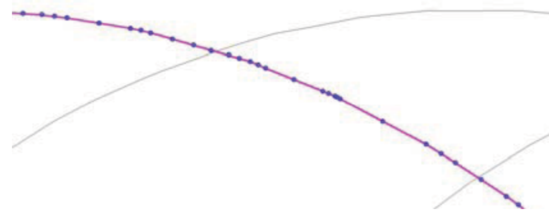
Hence, the algorithm of point reduction is proposed and reduced contour points are fitted into NURBS curves in AutoCAD. The procedure for reducing contour points is shown in Figure 12. For cable support example, the specified value of thresholds $\Delta\Theta$ is 7.5°, $\Delta\theta$ is 7.5°, and $\Delta\varepsilon$ is 0.3 mm. In the cable support example, original contour points of segmented lines are about 17,000 points. After the point reduction, there are only about 2,600 points. In other words, the file size decreases much after applying the point reduction operation.

After reducing the points, the point data are imported into AutoCAD, and the built-in command "SPLINE" is used to draw the NURBS contours directly. The enlarged contour drawings are shown in figure 13(a) and 13(b). It is obvious that the number of contour points in figure 13(a) is much larger than figure 13(b). The contours composed of segmented lines are shown in figure 14(a), and the contours composed of NURBS curves with C^1 continuity are shown in figure 14(b). The contour of NURBS curves is smoother than the contour of straight line segments.

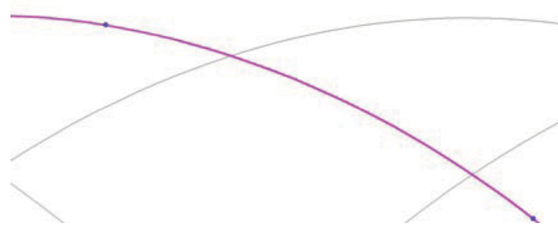


(a) Contour of segmented lines (b) Contour of NURBS

Figure 13. Enlarged drawing of one contour



(a) Segmented lines



(b) NURBS curve

Figure 14. More enlarged drawing of one contour

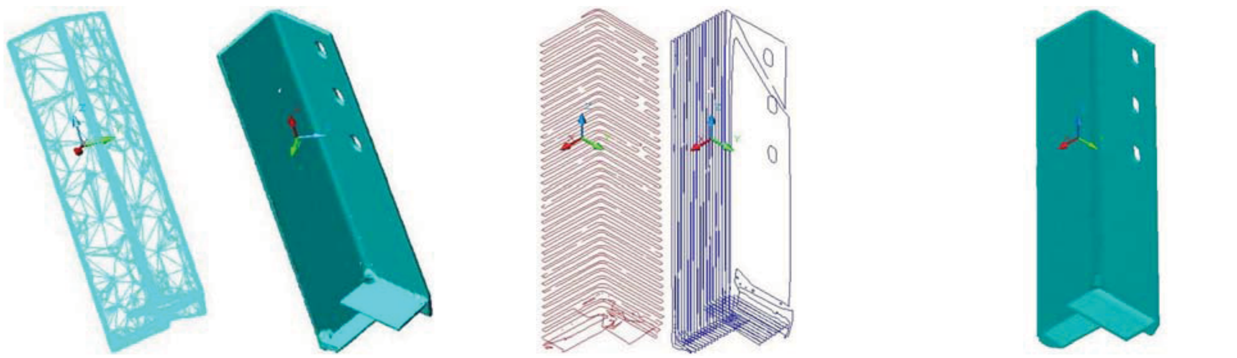
4. SOLID MODEL RECONSTRUCTION AND RESULTS

After obtaining a series of parallel contours, the solid model could be reconstructed from these smoothed slicing contours. In AutoCAD, the solid model is reconstructed by the "LOFT" operation, which is also supported by other general CAD software. A cable support, which is used to hold up power cables in an airplane, is used as a demo example. Figure 15(a) shows the object photo, and the final solid model reconstruction result of the cable support is shown in figure 15(b). The holes in the cable support are also reconstructed by similar approach, and subtracted from the model. The solid model reconstruction result of the other example, an angle plate, is shown as figure 16, and it also demonstrates that the approach addressed in this paper is able to reconstruct solid models of general objects.

(a) Photo of the cable support

(b) Reconstructed solid model for the cable support

Figure 15. Solid model reconstruction of a cable support



(a) Scanned STL model (b) Contours in two different direction (c) Reconstructed solid model

Figure 16. Solid model reconstruction of the angle plate

5. CONCLUSION

This paper presents an approach for solid model reconstruction. For an object with scanned data saved in a STL file, appropriate slicing planes are determined and fitted from the triangular facets by applying mesh segmentation and mesh redistribution operations. Then, parallel slicing contours of the STL model are extracted from the intersections of the mesh model and fitted slicing planes. Points of slicing contours are reduced and also refitted as smoothed NURBS curves. Finally, the solid model is reconstructed by the loft operation supported by general CAD software from smoothed slicing contours. Reconstructed solid models of a cable support and an angle plate are provided to show the capability and effectiveness of the proposed solid model reconstruction algorithms.

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