

ABSTRACT

Towed video is a commonly used underwater sensor. Spatially registered mosaics produced from video provide a method to integrate video data into Geographic Information Systems for concurrent analysis with other data layers. Video provides a level of spatial resolution one order of magnitude superior to that achieved by acoustic systems, thereby providing the resolution necessary to discriminate targets of potential interest in regions of heavy clutter. Herein a suite of software was written to integrate multiple sensors on a specific towed video system. The software written included data management, time synchronization, re-projection, radiometric enhancement and registration of video imagery. A new practical tool has been developed for operational surveys by the open scientific community.

Dedication

Family is the essence of one's existence, providing a foundation for growth and development, as well as a validation and legacy of one's contribution to society. A man does not easily balance his commitment to his family with a pursuit of advanced academic qualification at a university far separated from his home.

I dedicate this work to my children, James and Jessica. I am your past, you are what I hold dear for the future and my incentive to achieve.

To my wife Virginia who has set her career interests secondary to mine and endured many lonely days and nights tending the home fire, I offer this as a token of my love and appreciation of your life-long support, devotion and commitment to all of us.

Acknowledgements

I take this opportunity to acknowledge the patience of my mother and father, had I paid heed to your advice in my youth perhaps I would have achieved a degree a quarter of a century earlier.

Dave Wells and Larry Mayer were fundamental in the establishment of the Ocean Mapping Chair and smoothed my entry to the university. I first met Larry in 1988 at a meeting concerning the creation of a Multi-beam Mapping Program for Canada he expressed his concern that in his experience navies tended to unrealistically limit access to high quality bathymetry. I've kept this in mind and always made a conscious effort to set realistic limits upon data access.

The Bedford Institute of Oceanography (BIO) provides a collegial atmosphere that encourages synergies between various disciplines with interest in Ocean Research and Operations. In 1993 BIO welcomed the establishment of a navy cell in the institute. The cooperative efforts undertaken since then with the Canadian Hydrographic Service and the Geological Survey laid the groundwork of experience for me to commence this work.

The TOWCAM project represents the achievements through synergy that have been the hallmark of BIO over the years. I express my gratitude to Dave McKeown and Don Gordon for their assistance and encouragement, I hope this work is of some benefit to your project.

To my supervisor John Hughes-Clarke, whose assistance, advice and enthusiasm were key to this work, I express my humble thanks for the guidance you provided to this simple sailor.

Table of Contents

Abstract	i
Dedication	ii
Acknowledgements	iii
Table of Contents	iv
List of Figures	ix
List of Tables	x

CHAPTER 1 INTRODUCTION

1.1	Introduction	1
1.2	Report Contents	2
1.2.1	Chapter 2 – Background	3
1.2.2	Chapter 3 – Video Mosaicing	4
1.2.3	Chapter 4 – Creating Video Mosaics From TOWCAM	5
1.2.4	Chapter 5 – Conclusions and Future Directions	5

CHAPTER 2 – BACKGROUND

2.1.	Seabed Surveillance and Intervention	6
2.2	TOWCAM	14
2.2.1	Towcam System Description	14
2.2.2	TOWCAM In A Search Role	15
2.3.	Laser Underwater Camera Image Enhancer (LUCIE 2)	18
2.3.1	LUCIE Described	18
2.3.2	LUCIE As A Mapping Tool	19

2.3.2.1 LUCIE Optical and Video Specifications	20
2.3.3. LUCIE in a Towed Configuration	21
2.4 Video Mapping as a Surveillance Tool	23
CHAPTER 3 – VIDEO MOSAICING	
3.1 General	24
3.2 Mosaicing Techniques	24
3.2.1 Underwater Mosaicking	25
3.2.1.1 Sensor Only Mosaic	26
3.2.1.2 Estimated Motion and Image Matching	26
3.2.1.2.1 Optical Flow	26
3.2.1.2.2 MPEG Motion Vectors	27
3.2.1.3 Oblique Video and Image Registration	28
3.3 Lens Distortion	28
3.3.1 Radial Lens Distortion	29
3.4 Lighting Correction	30
3.4.1 CCD Camera Radiometric Correction	30
3.4.1.1 Dark Noise Image	30
3.4.1.2 Uniformly Lit Reference Image	31
3.4.1.3 Homomorphic Filtering	31
3.5 Mosaicing Scheme for TOWCAM Video	31
3.5.1 Camera Model	32
3.5.1.1 Image Correction	32
3.5.2 Export Mosaic to GIS	33

3.5.3	Conclusion	34
CHAPTER 4 – CREATING VIDEO MOSAICS FROM TOWCAM		
4.1	Introduction	35
4.2	Positioning and Attitude Sensing	35
4.3	Camera Calibration	36
4.3.1	Calibration Procedure	36
4.3.2	Calibration Results	38
4.3.2.1	Radial Distortion	38
4.3.2.2	Radiometric Correction	41
4.4	TOWCAM Data Description	42
4.4.1	Navigation and Telemetry Logging	42
4.4.1.1	Shipboard Navigation Data	43
4.4.1.2	TOWCAM Telemetry Data	43
4.4.2	Video Data Recording	44
4.5	TOWCAM Data Processing	45
4.5.1	Data Preparation	46
4.5.1.1	Time Synchronisation	47
4.5.1.2	Random Access Video Frames	48
4.5.1.3	Reformat and Combine Data	49
4.5.1.3.1	Extract Navigation Data	49
4.5.1.3.2	Merge Nav. & Telemetry Data	49
4.5.1.3.3	Median Filter APS Data	50
4.5.2	Export Video Frames	52

4.5.3 Position and Orient Video Frames	54
4.5.3.1 Estimation of Camera Position	55
4.5.4 Re-Project Video Frame	58
4.5.4.1 Radiometric Enhancement	58
4.5.4.2 Correction of Radial Distortion	59
4.5.4.3 Re-projection Function	59
4.5.4.4 Create Image of Weighted Values	62
4.5.5 Patch Frames to Mosaic and Export	63
4.5.5.1 Convert to OMG Format	64
4.5.5.2 Patch Frames to Mosaic	65
4.5.5.3 Export Geo-registered Mosaic	66
4.6 Conclusion	66

CHAPTER 5 – CONCLUSIONS AND FUTURE DIRECTIONS

5.1 General	67
5.2 Instrumentation Enhancements	67
5.2.1 Camera Heading	67
5.2.2 Vessel Pitch and Roll	68
5.2.3 Higher Data Frequency	68
5.2.4 Camera Calibration	68
5.2.5 Doppler Speed Log	69
5.3 Software and Processing Enhancements	69
5.3.1 Image Motion Estimation	69
5.3.2 OMG Header to Match Frame Mosaic	70

5.3.3	Adapt to Common User Interface	70
5.3.4	Radiometric Correction	70
5.4	Future Directions	70
REFERENCES		71
BIBLIOGRAPHY		75
APPENDICES		
Appendix 1	Sensor Offsets	76
A1.1	Shipboard GPS and Acoustic Tracking Transducer Geometry	76
A1.2	TOWCAM Vehicle Geometry	77
Appendix 2	Program Source Code and Shell Scripts	78
A2.1	mosProc.c	78
A2.2	filtNav.c	86
A2.3	newNav.c	92
A2.4	projNew.c	106
A2.5	Merge_Data	119
A2.6	toJHC	119
A2.7	corners.sh	120
Appendix 3	Sample Telemetry, Navigation and Mosaic Data	121
A3.1	Long-term Telemetry from TOWCAM	121
A3.2	Video Mosaic Composite	122
A3.2.1	Video Mosaic from Epoch 003930-003955	124
A3.2.2	Video Mosaic from Epoch 003950-004015	125
A3.2.3	Video Mosaic from Epoch 004010-004035	126

A3.2. Video Mosaic from Epoch 004033-004058	127
---	-----

Vita

List of Figures

Figure 1-1	An idealised image of TOWCAM	3
Figure 2-1	Deep Sea Intervention System	6
Figure 2-2	Phantom ROV	7
Figure 2-3	Diver suited up in CUMA2 Equipment	8
Figure 2-4	High Resolution sonar image of mine shape	9
Figure 2-5	Sonar image of glacial erratic boulders	10
Figure 2-6	Comparison of resolution	11
Figure 2-7	Sonar mosaic	12
Figure 2-8	Example of sonar mosaic image of an aircraft crash	13
Figure 2-9	TOWCAM II Vehicle	14
Figure 2-10	US Mk82 Bombs	16
Figure 2-11	TOWCAM video screen capture	17
Figure 2-12	LUCIE Principle of Operation	19
Figure 2-13	LUCIE 2 camera system	20
Figure 2-14	A high frequency sonar on LUCIE	21
Figure 2-15	Comparison of visible range results	22
Figure 3-1	Global Hawk surveillance UAV	24
Figure 3-2	Panoramic image	25
Figure 3-3	Mosaic of underwater pipeline	27
Figure 3-4	Computation of TOWCAM nominal frame overlap	32
Figure 3-5	Comparison of color versus grayscale	33
Figure 4-1	Basic setup used for quick video camera calibration	32

Figure 4-2	Video Frame of planar grid	38
Figure 4-3	Preliminary calibration image	39
Figure 4-4	Laminated paper grid imaged obliquely	40
Figure 4-5	Image projected to a flat plane	41
Figure 4-6	Video frame showing radiance pattern	42
Figure 4-7	Example lines of serial data found in a “.03e” file	43
Figure 4-8	First five lines from a “.03T” TOWCAM data file	44
Figure 4-9	Video frame showing time and position stamp	45
Figure 4-10	Data Processing Sequence	46
Figure 4-11	Layout of project directory tree	47
Figure 4-12	Example of “Vid_Info.txt” file	47
Figure 4-13	Cropped sections of two successive video frames	48
Figure 4-15	Graph of median filtered ORE Azimuth data	50
Figure 4-16	Record format for combined 1 Hertz data	51
Figure 4-17	Record format for 0.5 Hertz Acoustic Tracking Data	52
Figure 4-18	Example “tCode” shell	53
Figure 4-19	C functions “LenLatMin” and “LenLonMin”	55
Figure 4-20	Horizontal range calculation of TOWCAM	57
Figure 4-21	Horizontal Projection Error	58
Figure 4-22	Original video frame and re-projected frame	61
Figure 4-23	Image and Ground Plane coordinate system	62
Figure 4-24	Image of weight values	63
Figure 4-25	Re-projected section of video frame	64

Figure 4-26	Radial distortion corrected frame	.....65
Figure 4-27	Composite of a series of four 25 sec mosaics	.....66
Figure A1-1	CCGS Hudson sensor layout	.....76
Figure A3-1	Long-term Telemetry Data	.....121
Figure A3-2	Composite Mosaic	.....122
Figure A3-3	Navigation and Acoustic Positioning Data	.....123
Figure A3-4	Mosaic from Epoch 3930-3955	.....124
Figure A3-5	Mosaic from Epoch 3950-4015	.....125
Figure A3-6	Mosaic from Epoch 4010-4035	.....126
Figure A3-7	Mosaic from Epoch 4033-4058	.....127

List of Tables

Table 2-1 Resolution of Generic Seafloor Mapping Systems9

Table A1-1 Towcam Sensor Offsets77