

EMBEDDED VIDEO STABILIZATION SYSTEM ON FIELD
PROGRAMMABLE GATE ARRAY FOR UNMANNED AERIAL VEHICLE

MOHD FARIZAL FIRDAUS BIN MAZLAN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

APRIL 2017

Specially dedicated to my beloved parents Mazlan Bin Daud and Hasnah Binti
Yusoff.

ACKNOWLEDGEMENT

In the name of God, The Most Gracious and The Most Merciful. I am really grateful with His blessed that I am able to finish my thesis successfully within the period. I would like to express my gratitude to my parents and to my family for their support.

I would like to take this opportunity to extend my appreciation to both my supervisor, Dr. Musa bin Mohd Mokji and my co-supervisor Mr. Zulfakar bin Aspar for their guidance, supports, advices and encouragement upon the completion of this research.

Besides, I would like to thanks to my seniors Tang Jia Wei for his excellent advices during doing this research. Last but not least, many thanks to all my fellow friends in Embedded research lab and VECAD research lab who are given me support and motivation throughout this project.

ABSTRACT

Unmanned Aerial Vehicles (UAVs) equipped with lightweight and low-cost cameras have grown in popularity and enable new applications of UAV technology. However, the video retrieved from small size UAVs is normally in low-quality due to high frequency jitter. This thesis presents the development of video stabilization algorithm implemented on Field Programmable Gate Array (FPGA). The video stabilization algorithm consists of three main processes, which are motion estimation, motion stabilization and motion compensation to minimize the jitter. Motion estimation involves block matching and Random Sample Consensus (RANSAC) to estimate the affine matrix that defines the motion perspective between two consecutive frames. Then, parameter extraction, motion smoothing and motion vector correction, which are parts of the motion stabilization, are tasked in removing unwanted camera movement. Finally, motion compensation stabilizes two consecutive frames based on filtered motion vectors. In order to facilitate the ground station mobility, this algorithm needs to be processed onboard the UAV in real-time. The nature of parallelization of video stabilization processing is suitable to be utilized by using FPGA in order to achieve real-time capability. The implementation of this system is on Altera DE2-115 FPGA board. Full hardware dedicated cores without Nios II processor are designed in stream-oriented architecture to accelerate the computation. Furthermore, a parallelized architecture consisting of block matching and highly parameterizable RANSAC processor modules show that the proposed system is able to achieve up to 30 frames per second processing and a good stabilization improvement up to 1.78 Interframe Transformation Fidelity value. Hence, it is concluded that the proposed system is suitable for real-time video stabilization for UAV application.

ABSTRAK

Kenderaan udara tanpa manusia (UAV) yang dilengkapi dengan kamera ringan dan kos rendah telah meningkat kepopularan dan membolehkan penggunaan baru teknologi UAV. Walau bagaimanapun, video yang diambil dari UAV bersaiz kecil kebiasaannya berkualiti rendah kerana ketaran berfrekuensi tinggi. Tesis ini membentangkan pembangunan algoritma penstabilan video dalam Tatasusunan Get Boleh Aturcara Medan (FPGA). Algoritma penstabilan video terdiri daripada tiga proses utama iaitu anggaran gerakan, penstabilan gerakan dan pampasan gerakan untuk mengurangkan ketaran. Anggaran gerakan melibatkan pepadanan blok dan Persetujuan Sampel Rawak (RANSAC) untuk menganggarkan matrik afin yang mentakrifkan perspektif gerakan antara dua bingkai berturutan. Kemudian, pengekstrakan parameter, pelicinan gerakan dan pembetulan vektor gerakan, yang merupakan sebahagian penstabilan gerakan, ditugaskan untuk membuang pergerakan kamera yang tidak diinginkan. Akhir sekali, pampasan gerakan mengubah dua bingkai berturut-turut berdasarkan vektor gerakan yang ditapis. Bagi memudahkan pergerakan stesen di atas tanah, algoritma ini perlu diproses di atas UAV dalam masa-nyata. Sifat keselarian proses penstabilan video adalah sesuai dengan penggunaan FPGA bagi mencapai keupayaan video masa-nyata. Sistem ini dilaksanakan di papan Altera DE2-115 FPGA. Teras perkakasan khusus sepenuhnya tanpa pemproses Nios II direka dalam seni bina berorientasikan aliran untuk mempercepatkan pengiraan. Tambahan pula, satu seni bina pepadanan blok yang selari dan satu modul pemproses RANSAC yang boleh diparameterkan menunjukkan sistem yang dicadang mencapai pemprosesan sehingga 30 bingkai per saat dan perbaikan penstabilan yang baik iaitu sehingga 1.78 nilai Ketepatan Transformasi Antara Bingkai. Kesimpulannya menunjukkan bahawa sistem yang dicadangkan ini sesuai untuk sistem penstabilan video masa nyata bagi aplikasi UAV.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xi
	LIST OF FIGURES	xii
	LIST OF ABBREVIATIONS	xiv
	LIST OF SYMBOLS	xvi
	LIST OF APPENDICES	xvii
1	INTRODUCTION	1
	1.1 Background	1
	1.2 Problem Statement	2
	1.3 Project Objectives	4
	1.4 Project Scope	4
	1.5 Contributions	5
	1.6 Thesis Organization	5
2	LITERATURE REVIEW	6
	2.1 Video Stabilization	6
	2.2 Motion Estimation: Image Registration	7
	2.2.1 Feature-Based Method	8
	2.2.2 Area-Based Method	9

2.3	Motion Estimation: Robust Estimator	11
2.4	Motion Stabilization	12
2.5	Motion Compensation: Camera Motion Model	14
2.6	Field-Programmable Gate Array (FPGA) Implementation	15
2.7	Performance Test	17
2.8	Summary	19
3	METHODOLOGY	20
3.1	Motion Estimation: Block Matching	22
3.1.1	Extraction Process	22
3.1.2	Matching Process	25
3.2	Motion Estimation: Random Sample Consensus (RANSAC)	26
3.3	Motion Stabilization	28
3.3.1	Motion Vector Extraction	28
3.3.2	Motion Smoothing	29
3.3.3	Motion Vector Correction	32
3.4	Motion Compensation	34
3.4.1	Affine Transformation	34
3.5	Experimental Setup	36
3.6	DE2-115 FPGA development Board	37
3.7	Video Source	38
3.8	Summary	39
4	HARDWARE DEVELOPMENT	40
4.1	System Hardware Architecture	40
4.2	Process Flow	41
4.2.1	Data Flow	42
4.2.2	Pipeline Process	43
4.3	Motion Estimation Core	44
4.3.1	Switching Buffer	44
4.3.2	Block Matching	46
4.3.2.1	Line Buffer	47
4.3.2.2	Locator	50

4.3.2.3	<i>Extractor: Pixel Memory Array</i>	51
4.3.2.4	<i>Extractor: Memory Control Unit</i>	54
4.3.2.5	SAD Processor	56
4.3.2.6	Match Pair Finder	58
4.3.3	Random Sample Consensus (RANSAC)	59
4.3.3.1	External Control Unit	61
4.3.3.2	Internal Control Unit	62
4.3.3.3	Hypothesis Generator	64
4.3.3.4	Fitness Tester	66
4.4	Motion Stabilization Core	68
4.4.1	Average Moving Filter & Motion Vector Correction	69
4.5	Motion Compensation Core	70
4.5.1	<i>Affine Transform: Address Generator</i>	71
4.5.2	<i>Affine Transform: Affine Control Unit</i>	72
4.6	Frame Buffer	74
4.7	Summary	75
5	RESULT AND DISCUSSION	76
5.1	Software Analysis	76
5.2	Video Stabilization System Proposed Algorithm	76
5.2.1	Performance Analysis	84
5.3	Hardware Analysis	84
5.3.1	Stabilization Result	85
5.3.2	Performance Analysis	88
5.3.3	FPGA Resources Consumption	89
5.3.4	Timing Analysis	89
5.4	Comparison	91
5.4.1	Previous Work: Block Matching	91
5.4.2	Previous Work: RANSAC	92
5.4.3	Previous Work: FPGA Video Stabilization	92
6	CONCLUSION	94
6.1	Conclusion Remarks	94

		x
6.2	Future Work	95
REFERENCES		96
Appendix A		102

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Motion models [43]	15
2.2	ITF difference comparison between several video stabilization methods	19
3.1	Summary of the proposed algorithm	21
4.1	Input and output data for video stabilization system	42
4.2	States name	56
4.3	Pixel signal condition	56
4.4	Control Vector for memory array	56
4.5	Hardware implements pipeline stages	65
4.6	Fixed point precisions for hypothesis modelling module	66
5.1	ITF test (Software)	84
5.2	ITF test of <i>REALs</i> video set	88
5.3	ITF test of <i>UAVs</i> video set	88
5.4	Time taken to finish individual process (Hardware)	90
5.5	Comparison between proposed and main reference block matching	91
5.6	Comparison between proposed and main reference RANSAC	92
5.7	Summary of proposed method with two reference methods	93
5.8	Comparison result of proposed method with two reference methods	93

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Digital video stabilization steps	7
2.2	Lag phenomenon [36]	13
3.1	Overall proposed algorithm for video image stabilization	21
3.2	Graph of maximum surrounding frame displacement to number of search blocks for 640×480 image size	23
3.3	Position of template blocks for 10×8 search blocks	24
3.4	Smoothed horizontal translation motion vector	30
3.5	Smoothed horizontal translation motion vector with multiple number of points in moving average filter	32
3.6	Reverse affine transformation process	35
3.7	Prototype experimental setup	37
3.8	Layout of DE2-115 FPGA development board	38
3.9	Samples Unstable Video Frame (<i>UAV_I</i>). From left frame 50 th , frame 55 th , frame 60 th	39
4.1	Top view of video image stabilization system	41
4.2	Timing diagram of pipeline process for video image stabilization system	43
4.3	Motion estimation core	44
4.4	Hardware architecture for switching buffer	45
4.5	Hardware architecture for Block Matching module	47
4.6	Line buffer	48
4.7	Pixel window	49
4.8	Pixel position signal for 10×8 search blocks. M position is XY counter = (96, 90), Block counter = 12	51

4.9	Hardware architecture for memory array	52
4.10	Hardware architecture for Jay's memory array	52
4.11	Hardware architecture for memory element	54
4.12	Memory control unit FSM-Chart	55
4.13	Hardware architecture for SAD PE	57
4.14	Hardware architecture for original Score PE	58
4.15	Hardware architecture for match pair finder	59
4.16	Hardware architecture for RANSAC module	60
4.17	ASM-Chart for external control unit	61
4.18	ASM-Chart for internal control unit	63
4.19	Hardware architecture for fitness tester	68
4.20	Hardware architecture for motion stabilization	70
4.21	Hardware architecture for motion compensation	71
4.22	Hardware architecture for address generator	72
4.23	ASM-Chart for affine control unit	73
4.24	ASM-Chart for frame buffer control unit	75
5.1	Result of motion estimation	78
5.2	Result of smoothed translation motion vector	80
5.3	Result of affine transformation	81
5.4	Result of stabilized frame side by side comparison captured in software. Left side: Original frame. Right side: Stabilized frame output	83
5.5	Result of stabilized frame side by side comparison captured in real time. Left side: Original frame. Right side: Stabilized frame output.	87
5.6	Resource utilized	89
5.7	Fmax clock rate	89
5.8	Pie chart of time taken (%) to finish individual process (Hardware)	90

LIST OF ABBREVIATIONS

CV	-	Control Vector
DOF	-	Degree Of Freedom
EMV	-	Estimated Motion Vector
FAST	-	Features from Accelerated Segment Test
FIFO	-	First In First Out
FPGA	-	Field Programmable Gate Array
FPS	-	Frames Per Second
GPIO	-	General Purpose Input Output
HDL	-	Hardware Description Language
IIR	-	Infinite Impulse Response
ITF	-	Interframe Transformation Fidelity
KLT	-	Kanade-Lucas-Tomasi
LFSR	-	Linear Feedback Shift Register
LMS	-	Least Mean Square
LO-RANSAC	-	Locally Optimized - Random Sample Consensus
MAPSAC	-	Maximum a Posteriori Sample Consensus
ME	-	Motion Estimation
MLESAC	-	Maximum Likelihood Estimation Sample Consensus
MS	-	Motion Stabilization
MSE	-	Mean Square Error
MVI	-	Motion Vector Integration
NMV	-	New Motion Vector
NNC	-	Normalized Cross Correlation
PE	-	Processing Element
PPFM	-	Polynomial Fitting And Prediction Method

PROSAC	-	Progressive Sample Consensus
PSNR	-	Peak Signal-to-Noise Ratio
RANSAC	-	Random Sample Consensus
R-RANSAC	-	Randomized - Random Sample Consensus
SAD	-	Sum of Absolute Difference
SDRAM	-	Synchronous Dynamic Random Access Memory
SIFT	-	Scale Invariant Feature
SMV	-	Smooth Motion Vector
SOC	-	System On Chip
SRAM	-	Static Random-Access Memory
SSD	-	Sum of Squared Differences
SURF	-	Speeded up Robust Features
UAV	-	Unmanned Aerial Vehicles
UMV	-	Unwanted Motion Vector
USB	-	Universal Serial Bus
VGA	-	Video Graphic Array

LIST OF SYMBOLS

H_{affine}	-	Affine transformation
k	-	Maximum number of iterations in RANSAC
$MSE(I_n, I_{n+1})$	-	MSE between image n and next image
$PSNR(I_n, I_{n+1})$	-	PSNR between image n and next image
T	-	Threshold which defines the tolerance of a pair is inlier
SAD_{error}	-	SAD error rate

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Publication	102

CHAPTER 1

INTRODUCTION

1.1 Background

Currently, Unmanned Aerial Vehicle or UAV is getting more popular in a variety of applications. Video surveillance is one of the common applications in a UAV application. Basically, UAV is an aircraft without pilot onboard. UAV can be flown autonomously either based on pre-programmed flight plans or more complex dynamic automation systems. UAV also can be remotely controlled aircraft flown by a pilot at a ground control station. Nowadays, the size of UAV has shrunken to smaller vehicles [1]. There are many benefits by using small UAV such as high flexibility, small volume, lightweight and low cost. Lately, the optical surveillance capabilities of UAV have been increased greatly thanks to small and affordable on-board cameras [1]. Hence, it allows the small UAV to be used for a number of missions, including reconnaissance and attack roles [2]. UAVs are also ideal for missions that are too ‘dangerous, dirty or dull’ for manned aircraft. UAV is one of the safe and efficient methods for monitoring dangerous environments or for taking aerial photography (surveillance) [2].

There are three types of stabilizer can be used to stabilize the video. First type is optical image stabilization. The optical image stabilization systems function by

manipulates the image before it gets to the camera sensor [3]. When the lens moves, the light rays from the subject are bent relative to the optical axis, resulting in an unsteady image because the light rays are deflected. By shifting image stabilization lens group on a plane perpendicular to the optical axis to counter the degree of image vibration, the light rays reaching the image plane can be steadied. Two vibration-detecting sensors for yaw and pitch are used to detect the angle and speed of movement because vibrations might occur in both horizontal and vertical directions. An actuator moves the lens group horizontally and vertically thus counteracting the vibration and maintaining the stable picture [3].

On the other hand, the second type is mechanical image stabilization or gimbal. It involves stabilizing the entire camera. This type of stabilization can use a motion sensor as a gyroscope or mechanical devices such as shock absorbers for passively damp any kind of vibrations.

The last type is digital image stabilization system. This system use electronic processing to control image stability. Unlike optical image stabilization system, the image is manipulated after reaching the sensor. This system detects the camera vibration and it slightly moves the image so that it remains in the same place on the sensor.

1.2 Problem Statement

One of the common payloads in UAV applications is video surveillance. Due to UAV's conditions, the quality of video captured easily degraded with the jitter. Examples of UAV's conditions are high frequency vibration caused by the engine and unexpected quick movement of UAV. The jitter is defined as all the undesired

positional fluctuation of the image such as translation and rotation are added to the intentional motion of the camera.

The optical image stabilization requires very expensive and complex hardware, as well as a good inertial sensor such that it is able to detect the shaking position. Besides that, the mechanical stabilizers are not suitable for small and medium UAVs at the current time due to power consumption. Furthermore, some mechanical stabilizers are very complex to install and faced space constraint for the small and mobile UAV.

As for small, remotely controlled platform, the resources become an extremely important factor for the digital image processing. Some algorithms, having good performance, will always need complex computation. The high computation power yields two complications. First, the complex computation algorithm needs high performance CPU to execute the command. So, it will uses more power on the UAV for the image processing. Second, the complex computation algorithm need more time to complete the calculation. Hence, the output becomes non-real time.

On the other hand, simple algorithm for digital image stabilization that is used by many handheld cameras or compact cameras will not solve the slow frequency swaying. Furthermore, most of the digital image stabilization algorithm available on market is to compensate the camera vibration while capturing still image.

1.3 Project Objectives

Two main objectives have been highlighted in this project as below:

- i. The first objective is to develop a video stabilization algorithm to minimize the unsteady video due to vibration. Hence, the viewer should be able to extract information from the video with ease.
- ii. The second objective is to implement the proposed video stabilization algorithm on Field Programmable Gate Array (FPGA) for real time video processing. Since the video stabilization algorithm requires general personal computer capability to be done, thus FPGA implementation increases the portability to solve the needs of bulky power and hungry desktop processor.

1.4 Project Scope

There are several scopes have been outlined in order to achieve the objective of this project. The video view will be analysed in this project is only aerial view or UAV view. The video surveillance recorded is only on land and beach scene only. The beach scene is not an open sea view which only has uniform scene. As for simulation of the algorithm, software MATLAB will be used. The hardware optimization for the algorithm is not necessary. For hardware part, the algorithm will be implemented on Altera FPGA board only. Thus, software Altera Quartus II will be used for hardware algorithm development. The motion camera modelling used for this project is affine motion. The project will limited the research to only focus on translation motion. The motion compensation algorithm will ignore the rotational motion. The video will be processed in the grayscale. Finally, the hardware implementation is targeted to achieve real-time capability at 30 frames per second (fps) in VGA resolution.

1.5 Contributions

The contribution of this thesis is proposed a selection of video stabilization algorithm for UAV application. The algorithm is described suitable to be implemented on hardware FPGA for real-time processing capability while maintaining the main function which is removing unwanted movement mainly caused by vibration from UAV's engine.

The hardware system is designed in fully hardware without the aid from embedded software processor, Nios II in order to increase the processing speed. Furthermore, the hardware implementation for motion estimation also is designed to do computation in parallel. Besides, the RANSAC module is developed with the processor that can be parameterized in order to speed up the process.

1.6 Thesis Organization

This thesis is organized into six chapters. The first chapter has presented the problem statements, project objectives and project scopes. Chapter 2 reviews the previous work related to this project. Chapter 3 explains the proposed algorithm applied for the video image stabilization along with the experimental setup. Chapter 4 describes the FPGA hardware implementation of each process. Chapter 5 documents the result and analysis done throughout this project. Chapter 6 summarizes the project and suggestion for future work.

REFERENCES

1. Carr, E. B. Unmanned Aerial Vehicles: Examining the Safety, Security, Privacy and Regulatory Issues of Integration into US Airspace. *National Centre for Policy Analysis (NCPA)*. Retrieved on September. 2013. 23.
2. Mai, Y., Zhao, H. and Guo, S. The Analysis of Image Stabilization Technology Based on Small-UAV Airborne Video. Proceedings of the *International Conference on Computer Science and Electronics Engineering*: IEEE. 2012. 586-589.
3. Alharbi, M. A. Fast Video Stabilization Algorithms. *Master thesis*. Air Force Institute of Technology Air University. 2006.
4. Jia, C., Sinno, Z. and Evans, B. L. Real-Time 3D Rotation Smoothing for Video Stabilization. Proceedings of the *Asilomar Conference on Signals, Systems, and Computers*: IEEE. 2014. 673-677.
5. Torr, P. H. and Zisserman, A. Feature Based Methods for Structure and Motion Estimation. Proceedings of the *International workshop on vision algorithms*: Springer. 1999. 278-294.
6. Zitova, B. and Flusser, J. Image Registration Methods: A Survey. *Image and vision computing*. 2003. 21(11): 977-1000.
7. Lowe, D. G. Distinctive Image Features from Scale-invariant Keypoints. *International journal of computer vision*. 2004. 60(2): 91-110.
8. Bay, H., Ess, A., Tuytelaars, T. and Van Gool, L. Speeded-up Robust Features (SURF). *Computer vision and image understanding*. 2008. 110(3): 346-359.
9. Rosten, E., Porter, R. and Drummond, T. Faster and Better: A Machine Learning Approach to Corner Detection. *IEEE Transactions on Pattern Analysis and Machine Intelligence*. 2010. 32(1): 105-119.

10. Santhaseelan, V. and Asari, V. K. An Adaptive Parameterization Method for SIFT Based Video Stabilization. Proceedings of the 39th Applied Imagery Pattern Recognition Workshop (AIPR): IEEE. 2010. 1-6.
11. Hu, R., Shi, R., Shen, I.-f. and Chen, W. Video Stabilization Using Scale-invariant Features. Proceedings of the 11th International Conference on the Information Visualization: IEEE. 2007. 871-877.
12. Walha, A., Wali, A. and Alimi, A. M. Video Stabilization for Aerial Video Surveillance. AASRI Procedia. 2013. 4: 72-77.
13. Pinto, B. and Anurenjan, P. Video Stabilization using Speeded Up Robust Features. Proceedings of the International Conference on Communications and Signal Processing (ICCSP): IEEE. 2011. 527-531.
14. Zhou, M. and Asari, V. K. A Fast Video Stabilization System Based on Speeded-up Robust Features. Proceedings of the International Symposium on Visual Computing: Springer. 2011. 428-435.
15. Wang, Y., Hou, Z., Leman, K. and Chang, R. Real-Time Video Stabilization for Unmanned Aerial Vehicles. Proceedings of the MVA. 2011. 336-339.
16. Patel, P. M. and Shah, V. M. Image Registration Techniques: A Comprehensive Survey. International Journal of Innovative Research and Development. 2014. 3(3): 68-78.
17. Wang, L., Hu, W. and Tan, T. Recent Developments in Human Motion Analysis. Pattern recognition. 2003. 36(3): 585-601.
18. Vazquez, M. and Chang, C. Real-time Video Smoothing for Small RC Helicopters. Proceedings of the Systems, Man and Cybernetics: IEEE. 2009. 4019-4024.
19. Yang, S.-H. and Jheng, F.-M. An Adaptive Image Stabilization Technique. Proceedings of the Systems, Man and Cybernetics: IEEE. 2006. 1968-1973.
20. Vella, F., Castorina, A., Mancuso, M. and Messina, G. Digital Image Stabilization by Adaptive Block Motion Vectors Filtering. IEEE Transactions on Consumer Electronics. 2002. 48(3): 796-801.
21. Auberger, S. and Miro, C. Digital Video Stabilization Architecture for Low Cost Devices. Proceedings of the 4th International Symposium on Image and Signal Processing and Analysis: IEEE. 2005. 474-479.

22. Tanakian, M., Rezaei, M. and Mohanna, F. Real-time Video Stabilization by Adaptive Fuzzy Filtering. Proceedings of the *1st International eConference on Computer and Knowledge Engineering (ICCCKE)*: IEEE. 2011. 126-131.
23. Ko, S.-J., Lee, S.-H. and Lee, K.-H. Digital Image Stabilizing Algorithms Based on Bit-plane Matching. *IEEE Transactions on Consumer Electronics*. 1998. 44(3): 617-622.
24. Battiato, S., Gallo, G., Puglisi, G. and Scellato, S. SIFT Features Tracking for Video Stabilization. Proceedings of the *14th International Conference on Image Analysis and Processing (ICIAP)*: IEEE. 2007. 825-830.
25. Li, Z. and Wang, J. Least Squares Image Matching: A Comparison of the Performance of Robust Estimators. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2014. 2(1): 37.
26. Choi, S., Kim, T. and Yu, W. Robust Video Stabilization to Outlier Motion using Adaptive RANSAC. Proceedings of the *International Conference on Intelligent Robots and Systems*: IEEE. 2009. 1897-1902.
27. Fischler, M. A. and Bolles, R. C. Random Sample Consensus: A Paradigm for Model Fitting with Applications to Image Analysis and Automated Cartography. *Communications of the ACM*. 1981. 24(6): 381-395.
28. Torr, P. H. and Zisserman, A. MLESAC: A New Robust Estimator with Application to Estimating Image Geometry. *Computer Vision and Image Understanding*. 2000. 78(1): 138-156.
29. Matas, J. and Chum, O. Randomized RANSAC with $T_{d,d}$ Test. *Image and Vision Computing*. 2004. 22(10): 837-842.
30. Chum, O. and Matas, J. Matching with PROSAC-progressive Sample Consensus. Proceedings of the *Computer Society Conference on Computer Vision and Pattern Recognition (CVPR)*: IEEE. 2005 220-226.
31. Chum, O., Matas, J. and Kittler, J. Locally Optimized RANSAC. *Pattern Recognition*: Springer. 2003. 236-243.
32. Torr, P. H. S. Bayesian Model Estimation and Selection for Epipolar Geometry and Generic Manifold Fitting. *International Journal of Computer Vision*. 2002. 50(1): 35-61.
33. Engelsberg, A. and Schmidt, G. A Comparative Review of Digital Image Stabilising Algorithms for Mobile Video Communications. *IEEE Transactions on Consumer Electronics*. 1999. 45(3): 591-597.

34. Tanakian, M., Rezaei, M. and Mohanna, F. Digital Video Stabilization System by Adaptive Motion Vector Validation and Filtering. Proceedings of the *International conference on communication engineering*. 2010. 165-183.
35. Ertürk, S. Image Sequence Stabilisation: Motion Vector Integration (MVI) Versus Frame Position Smoothing (FPS). Proceedings of the *2nd International Symposium on Image and Signal Processing and Analysis, ISPA: IEEE*. 2001. 266-271.
36. Dong, J., Xia, Y., Yu, Q., Su, A. and Hou, W. Instantaneous Video Stabilization for Unmanned Aerial Vehicles. *Journal of Electronic Imaging*. 2014. 23(1). 1-10.
37. Rawat, P. and Singhai, J. Adaptive Motion Smoothing for Video Stabilization. *International Journal of Computer Applications*. 2013. 72(20): 14-20.
38. Güllü, M. K. and Ertürk, S. Membership Function Adaptive Fuzzy Filter for Image Sequence Stabilization. *IEEE Transactions on Consumer Electronics*. 2004. 50(1). 1-7.
39. Ko, S.-J., Lee, S.-H., Jeon, S.-W. and Kang, E.-S. Fast Digital Image Stabilizer Based on Gray-coded Bit-plane Matching. *IEEE Transactions on Consumer Electronics*. 1999. 45(3). 598-603.
40. Kancharla, T. and Gindi, S. A Real Time Video Stabilization Algorithm. *Advances in Computing and Communications: Springer*. 349-357; 2011.
41. Pan, Z. and Ngo, C.-W. Selective Object Stabilization for Home Video Consumers. *IEEE Transactions on Consumer Electronics*. 2005. 51(4). 1074-1084.
42. Litvin, A., Konrad, J. and Karl, W. C. Probabilistic Video Stabilization using Kalman Filtering and Mosaicing. Proceedings of the *Electronic Imaging on International Society for Optics and Photonics*. 2003. 663-674.
43. Cayón, R. J. O. Online Video Stabilization for UAV. Motion Estimation and Compensation for Unnamed Aerial Vehicles. *Master of Science Thesis. Politecnico di Milano*; 2013.
44. Johansen, D. L. Video Stabilization and Target Localization using Feature Tracking with Small UAV Video. *Master of Science Thesis. Brigham Young University*; 2006.

45. Toledo, F. J., Martinez, J. J. and Ferrández, M. FPGA-based Platform for Image and Video Processing Embedded Systems. Proceedings of the *3rd Southern Conference on Programmable Logic*: IEEE. 2007. 171-176.
46. Damez, L., Sieler, L., Landrault, A. and Dérutin, J. P. Embedding of a Real Time Image Stabilization Algorithm on a Parameterizable SoPC Architecture a Chip Multi-processor Approach. *Journal of Real-Time Image Processing*. 2011. 6(1). 47-58.
47. Piotrowski, R., Szczepanski, S. and Koziel, S. FPGA-Based Implementation of Real Time Optical Flow Algorithm and Its Applications for Digital Image Stabilization. *International Journal on Smart Sensing & Intelligent Systems*. 2010. 3(2). 253-272.
48. Yabuki, T. and Yamaguchi, Y. Real-time Video Stabilization on an FPGA. Proceedings of the *International Conference on Smart Structures and Systems ICSSS*: IEEE. 2013. 114-119.
49. Li, G. FPGA Implementation of Real-time Digital Image Stabilization. Proceedings of the *Selected Proceedings of the Photoelectronic Technology Committee Conferences*. 2013. 1-7.
50. Tang, J. W., Shaikh-Husin, N., Sheikh, U. U. and Marsono, M. N. FPGA-Based Real-Time Moving Target Detection System for Unmanned Aerial Vehicle Application. *International Journal of Reconfigurable Computing*. 2016. 1-16.
51. Tang, J. W., Shaikh-Husin, N. and Sheikh, U. U. FPGA Implementation of RANSAC Algorithm for Real-time Image Geometry Estimation. Proceedings of the *Student Conference on Research and Development SCOREd*: IEEE. 2013. 290-294.
52. Patterson, D. A. and Hennessy, J. L. Computer Organization and Design: The Hardware/software Interface, *San Francisco, California, Morgan Kaufmann Publisher, Inc.* 1998.