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

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

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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 pemadanan 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 membuangkan pergerakan kamera yang tidak diingini. 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 pemadanan blok yang selari dan satu modul pemproses RANSAC yang boleh diparameterkan menunjukkan sistem yang dicadang mencapai pemprosesan sehingga 30 bingkai per saat dan pembaikan 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.

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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
PFPM	-	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

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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.

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