UNIVERSITI PUTRA MALAYSIA

BLOTCH REMOVAL USING MULTI-LEVEL SCANNING, SHAPE ANALYSIS, AND META HEURISTIC TECHNIQUES

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By

MOHAMMAD REZA KHAMMAR

Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

July 2015

DEDICATIONS

To

My lovely family
And my dear parents

BLOTCH REMOVAL USING MULTI-LEVEL SCANNING, SHAPE ANALYSIS, AND META HEURISTIC TECHNIQUES

By

MOHAMMAD REZA KHAMMAR

July 2015

Chairman : **Assoc. Prof. Mohammad Hamiruce Marhaban, PhD**
Faculty   : **Engineering**

Valuable resources of artistic, historical, and cultural development of human life are stored in huge number of archives. These archives are suffering from a diversity of degradations and need to be restored. Blotches refer to the major degradations that mostly affect old films. In the current techniques of blotch detections, when high correct detection is required, the number of false alarms is high. Therefore, error in detection can cause some unnecessary changes in the uncorrupted pixels. On the other hand, due to restoration of blotches, fidelity may be affected and decreased because of the complex scene and large areas which are common in old archives. Thus, this research was aimed to enhance the performance of blotch detection comparing to the other available methods and to find a way to reconstruct blotches regardless of their sizes and scene complexity.

In order to remove blotches from digitized old archives, two steps are necessary: detection of the position of blotches and restoration of the missing data. Regarding the detection, a post processing method based on a combination of pixel-based and objects-based methods was proposed. This post processing algorithm was provided based on a multi-level scanning and shape analysis which was presented for the better performance of high correct detection and lower false alarms for each given threshold. After identifying the position of blotches, reconstruction of missing data was the next step.

Interpolation was organized based on just spatial information, and also spatial and temporal information. If the sizes of blotches are small, for example, less than 20 by 20 pixels, the process of reconstruction can be handled with traditional heuristic or previous model based methods, such as, Auto Regressive and Markov Random Field methods. Interpolation of the missing data for large area based on heuristic methods do not lead to a reasonable result, but the meta-heuristic techniques have the ability to remove small and large areas with better fidelity even in a scene with a complex background. Genetic algorithm and multi-layer back propagation neural network algorithm were adopted and consequently applied to a variety of benchmark samples of image sequences. These methods were proposed to find the missing data in a better way than the existing approaches.

The final results were objectively and subjectively evaluated. Sign, Car, and Calendar image sequences were corrupted artificially with blotches of random size, shapes, and intensity. For objective assessment, in the field of detection of blotches, false alarms and correct detection were calculated and comprehensive comparisons were prepared based on Receiver Operation Characteristic. In addition, Mean Square Error, Normal Correlation, Image Enhancement Factor, and Peak Signal to Noise Ratio were calculated for restoration and the results were collected for comparison. The subjective evaluation also was done by requesting some respondent to judge the results. The algorithms were applied to two real image sequences which were contaminated to unknown blotches and the results were extracted for evaluation of proposed methods.

Finally, a successful platform including blotch detection and correction was presented in this study, the proposed blotch removal approaches proves to have the potential to be applied to real blotches to restore old archives in real restoration process.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENYINGKIRAN KETOMPOKAN MENGGUNAKAN PENGESANAN PELBAGAI LAPISAN, ANALISIS BENTUK DAN TEKNIK META HEURISTIK

Oleh

MOHAMMAD REZA KHAMMAR

Julai 2015

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Khazanah seni, sejarah, dan pembangunan budaya kehidupan manusia disimpan di dalam arkib dalam jumlah yang besar. Arkib tersebut mengalami kepelbagaian degradasi dan perlu dipulihkan. Ketompokan merujuk kepada degradasi utama yang kebanyakannya memberi kesan kepada filem-filem lama. Dalam teknik sedia ada bagi pengesanan ketompokan, apabila pengesanan benar yang tinggi diperlukan, bilangan isyarat palsu juga adalah tinggi. Oleh itu, pengesanan salah boleh menyebabkan beberapa perubahan yang tidak perlu dalam piksel yang tidak tercela. Sebaliknya, disebabkan oleh pemulihan ketompokan, fideliti mungkin terjejas dan merosot disebabkan oleh adegan kompleks dan kawasan luas yang menjadi kebiasaan di arkib lama. Oleh itu, kajian ini bertujuan untuk meningkatkan prestasi pengesanan ketompokan berbanding dengan kaedah sedia ada dan mencari jalan untuk membina semula ketompokan tanpa mengira saiz dan kerumitan adegan.

Dalam usaha untuk menghapuskan ketompokan daripada arkib digital yang lama, dua langkah yang perlu diambil: pengesanan kedudukan ketompokan dan pemulihan data yang hilang. Mengenai pengesanan, pendekatan pasca pemprosesan berdasarkan gabungan kaedah berasaskan piksel dan yang berdasarkan objek telah dicadangkan. Algoritma pasca pemprosesan ini telah disediakan berdasarkan pada pengesanan pelbagai lapisan dan analisis bentuk yang telah dikemukakan untuk meningkatkan prestasi pengesanan benar dan mengurangkan isyarat palsu untuk setiap nilai ambang. Selepas mengenal pasti kedudukan ketompokan, langkah seterusnya adalah pemulihan data yang hilang. Interpolasi dianjurkan berdasarkan hanya maklumat ruang, atau spatial dan maklumat sementara. Sebagai contoh, jka saiz ketompokan kecil, iaitu kurang daripada 20 darab 20 piksel, proses pembinaan semula boleh dikendalikan dengan kaedah heuristik konvensional atau kaedah berasaskan model, seperti regresif-auto dan kaedah medan rawak Markov. Interpolasi data hilang untuk kawasan besar berdasarkan pendekatan heuristik tidak membawa kepada keputusan yang baik, tetapi pendekatan meta heuristik mempunyai keupayaan untuk mengeluarkan kawasan kecil dan besar dengan fideliti yang lebih baik walaupun untuk adegan berlatarbelakang kompleks. Algoritma genetik dan algoritma pelbagai lapisan rambatan balik rangkaian neural telah digunakan untuk beberapa sampel jujukan imej. Kaedah-kaedah ini telah

dicadangkan untuk mencari data hilang dengan cara yang lebih baik daripada pendekatan sedia ada.

Keputusan akhir telah dinilai secara objektif dan subjektif. Jujukan imej bahasa isyarat, kereta, dan kalender telah dirosakan secara buatan dengan ketompokan yang rawak dari segi saiz, bentuk dan intensiti. Untuk penilaian objektif, dalam bidang pengesanan ketompokan, isyarat palsu dan pengesanan benar telah dikira dan perbandingan komprehensif telah disediakan berdasarkan kepada 'Receiver Operation Characteristic". Di samping itu, ralat min kuasa dua, korelasi normal, faktor peningkatan imej, nisbah puncak signal kepada hingar telah dikira untuk pemulihan dan keputusan telah diambil untuk perbandingan. Penilaian subjektif juga telah dilakukan dengan meminta beberapa responden untuk menilai keputusan. Algoritma telah digunakan dalam dua jujukan imej sebenar yang tercemar kepada ketompokan tidak diketahui dan keputusan telah diambil untuk penilaian bagi cadangan kaedah.

Akhir kata, platform yang berjaya termasuklah pengesanan dan pemulihan ketompokan telah dibentangkan dalam kajian ini. Pengesanan ketompokan yang dicadangkan terbukti mempunyai potensi untuk digunakan bagi mengesan kedudukan ketompokan sebenar dalam memulihkan arkib lama.

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I certify that a Thesis Examination Committee has met on 28 July 2015 to to conduct the final examination of Mohammad Reza Khammar on his thesis entitled "Blotch Removal using Multi-Level Scanning, Shape Analysis, and Meta Heuristic Techniques" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

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Date: 22 September 2015

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This thesis was submitted to the senate of Universiti Putra Malaysia and has been accepted as fulfilment the requirements for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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School of graduate studies
Universiti putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:
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- quotations, illustrations and citations have been duly referenced
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Declaration by Members of Supervisory Committee

This is to confirm that:
- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

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2DAR	Two dimensional AR model
3DAR	Three dimensional AR model
AR	Autoregressive
ADF	Adaptive Median Filter
AURORA	Arbeitsgemeinschaft der offentlich – rechtlichen P undfunkanstalten der Bundesrepublik Deutschland
ARD	Automated Restoration of Driginal film and video Archives British
BBC	British Broadcasting Corporation
BPNN	Back Propagation Neural Network
BRAVA	Broadcast Restoration of Archives by Video Analysis
BFGS	Broyden, Fletcher, Goldfarb, and Shanno
CNN	Cable News Network
CCF	Cross-Correlation Function
DBN	Dynamic Bayesian Network
FFBP	Feed Forward Back Propagation
HMM	Hidden Markov Model
INA	Institut National de L'Audiovisuel
IRIB	Islamic Republic of Iran Broadcasting
IEF	Image Enhancement Factor
MLFF	Multi-Layer Feed-Forward
MAE	Mean Absolute Error
MC	Markov Chain
ME	Motion Estimation
MMF	Multilevel Median Filter
MPEG	Motion Picture Experts Group
MLSSA	Multi-Level Scanning & Shape Analysis
MRF	Markov Random Field
MSR	Mean Square Error
MV	Motion Vector
NN	Neural Network
NC	Normal Correlation
GA	Genetic Algorithm
PDC	Pixel Difference Classification
PSNR	Peak Signal to Noise Ratio
ROC	Receiver Operating Characteristic
ROD	Rank Order Detector
SAD	Sum of Absolute Difference
SDI	Spike Detection Index
SNR	Signal to Noise Ratio
SDI	Spike Detection Index
SMF	Standard Median Filter

CHAPTER 1

INTRODUCTION

1.1   Background and Motivation

Even with the advancement of new technologies, video enhancement and restoration systems are still important. There are several positions in which recorded image sequences will possibly suffer from severe corruptions (Harvey & Marshall, 1997). The low quality of recorded image sequences may be due to, for example, lack of or uncontrollable recording environments, such as many applications in astronomy, medical imaging, and forensic sciences. Another function of video enhancement and restoration is that of maintaining the video tapes and motion pictures which are documented over the last decades (A. Kokaram et al., 2002). These distinctive archives are fading quickly due to aging effects of physical reels of film and magnetic tapes that convey the information.

These valuable resources of artistic, historic, and cultural development of human life are stored in a huge number of archives in British Broadcasting Corporation (BBC), Cable News Network (CNN), Institut National de L'Audiovisuel (INA), and other local broadcasters which belong to different countries like Islamic Republic of Iran Broadcasting (IRIB). These archives are suffering from a variety of degradations and need preservation and restoration. Most of them are in a breakable position which decreases their worth frequently (P. M. B. van Roosmalen, 1999). Another motivation for video restoration is that digital broadcasters want to create new channels (Ghaderi & Kasaei, 2004), thus, the broadcasters need new programing. Enormous collection of old archives can be considered as a cheap alternative option comparing to the high price of producing new programs, but reusing them is possible when their quality is enhanced approximately to the new product's level (A. C. Kokaram, 1993). Video restoration has been essential in these applications not only to promote the visual quality, but also to raise the performance of the following tasks, such as image and video investigation and understanding (Schallauer, Bailer, Morzinger, Furntratt, & Thallinger, 2007). A complete workflow of preservation, conversion, restoration, and storage to access and delivery is presented in Figure 1.1 (Addis, Choi, & Miller, 2005).

Basically, archives can include different medias such as video, film, and audio (J. B. Thompson, 2013). In order to apply any digital algorithm for restoration purposes, first, all of the archived motion pictures and videos are converted from their original format which can be either film reels or magnetic tapes into digital media. Then, these new format of archives are investigated for all kind of possible degradations. After that, the best efforts are done to remove defects and enhance the quality of image sequences as much as possible. Figure 1.1 is showing the different tasks related to the old archives in terms of conversion, preservation, restoration, storage, metadata and finally delivery for a variety of applications. The main production chain is the journey from analogue to digital material, including, stock evaluation, identification and selection, digitization process and its control, restoration, storage, production of content information (metadata) allowing for access, and finally delivery to the users.

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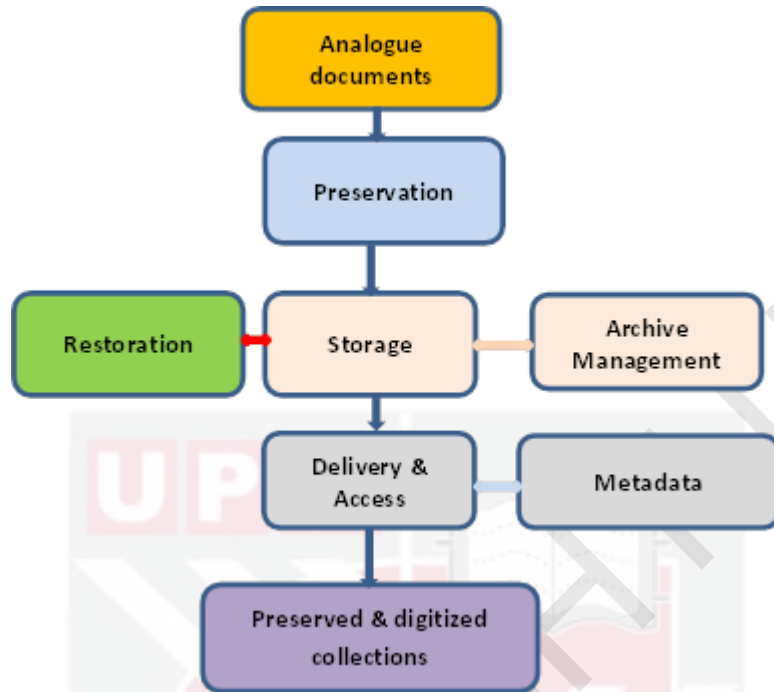
Figure 1.1: Work Breakdown of Preservation and Restoration Old Multimedia Archives.

In this study which is concerned about the improvement of restoration algorithms for film and video archives, the researcher made sure that old archives are converted to digital format before. In addition, the format of these digital media was not under investigation, because the researcher assumed that all frames are considered as a chain of image sequences. Due to restoration, automated image and video restoration approaches are desirable because of the large amount of archives (Kozlov, Petukhov, & Zheludev, 2010). Moreover, it is a tedious activity to detect and then remove artifacts manually through traditional methods (Huo, Tan, He, & Hu, 2013). The term semi-automated shows the efforts of the researchers to reduce the amount of parameters which is necessary to define for the user before applying the restoration process for a given image sequences. Hence, different algorithms can be evaluated based on computational complexity and accuracy, as well as, user dependency. Therefore, this is a requirement for an automated device of image sequences restoration due to the huge volumes of archived film and video and commercial limitations. Existing commercial restoration system tools need a lot of operator intervention, and hence, do not let for automatic restoration of most common artifacts (A. C. Kokaram, 1993). As a result, the field of image sequence restoration has been an active research topic since 1970's.

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large variety of artifacts are available in film and video archives, and so, finding a single algorithm which can be able to restore these artifacts is impractical, hence, different algorithms are necessary to cover all of them. Moreover, a modular artifact detection and removal can provide the opportunity to implement a restoration system with the ability to utilize parallel computing in order to reduce the total running time in some cases (P. M. B. van Roosmalen, 1999). Figure 1.2 shows the block diagrams of an image sequence restoration system. The input of restoration system is digital image sequences instead of video tapes or physical reels of film. This obviously indicates that despite the type of original format of sources and their possible coding, they have been quantized by expert people and applied to the restoration system. Image sequences are a serial of digital frames which come one after another.
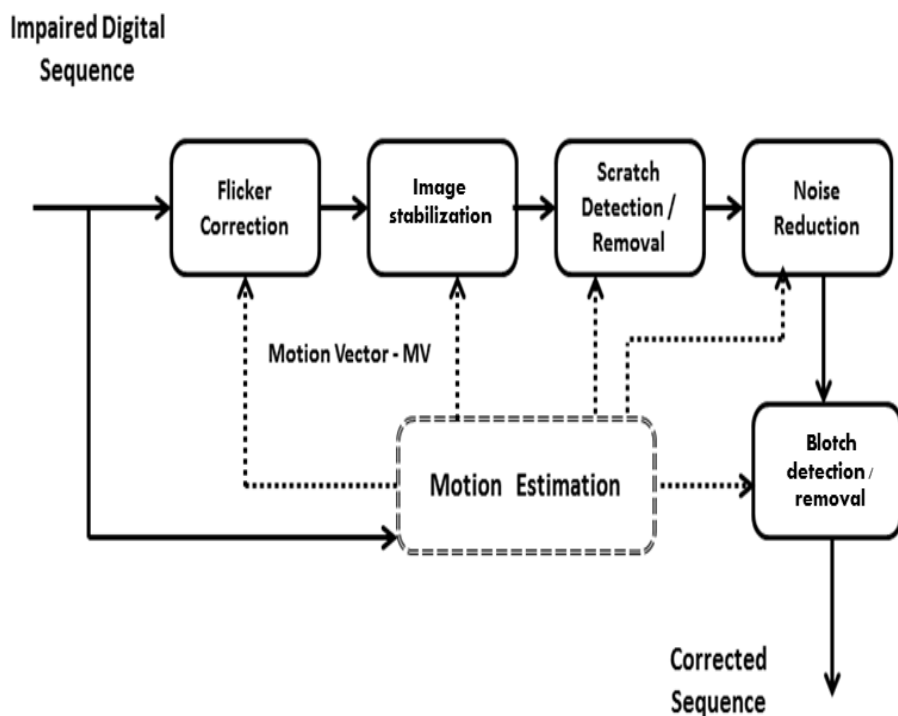
Figure1.1: General Block Diagram of a Modular Image Sequence Restoration System.

Blotches refer to the major degradations that mostly affect old archives (A. C. Kokaram, 1993). They randomly occur in the frames as dark spots inside the brighter surrounding area or bright spots inside the darker surrounding area and have arbitrary size, shape, and intensity. There are several factors causing blotches on films, such as, covering the dirt spots on the frames, damage of the gelatin on the film, and the physical interaction of the film mate rial with projecting tools (Tilie, Laborelli, & Bloch, 2006). The research have shown that it is rarely possible that two blotches

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happen at the same positions in two consecutive frames; it means that the temporal discontinuity is the most important characteristic of blotches which helps to detect them (Chong, Liu, Goh, & Krishman, 1997). After detection, interpolations of the missing data is vital (A. C. Kokaram, Morris, Fitzgerald, & Rayner, 1995b). Detection and interpolation of blotches are studied in this research.

Figure 1.3 demonstrates the source of different artifacts in a chain of recording, storing, transferring, conversion and digitization for film and video (P. M. B. van Roosmalen, 1999). This information for a new data acquisition system can help us to avoid contamination of new product by these defects, but as for old archives, the final footage is already polluted with different defects. Therefore, all efforts should focus on how to detect and restore them regardless of the time they had joined the original signal.

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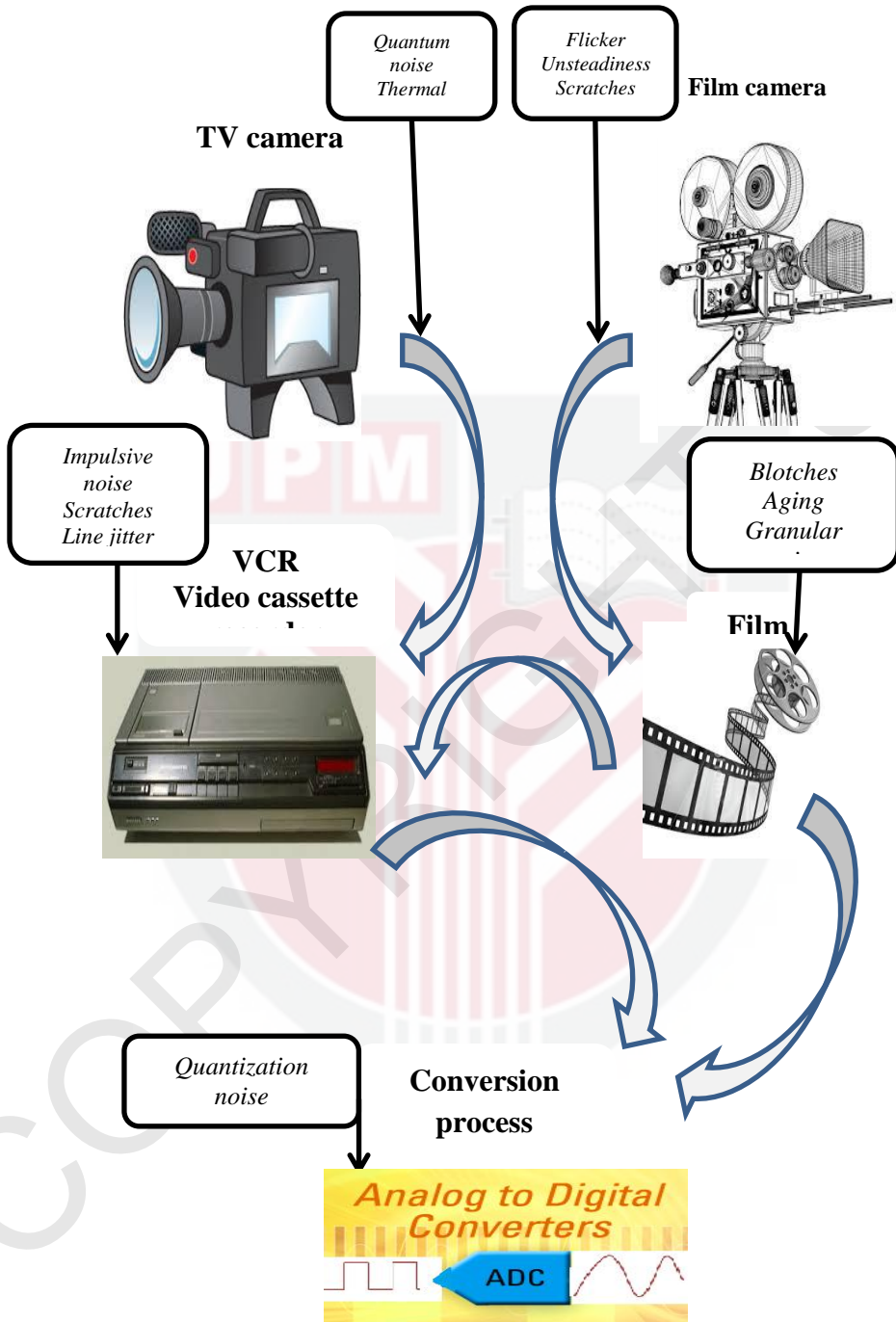
Figure1.2: General Block Diagram of a Modular Image Sequence Restoration System.

1.2 Problem Statement

In terms of film and video restoration, automated or at least semi-automated restoration methods are desirable because of the large amount of archives (Kozlov et al., 2010). Hence, three items are important aspects for different algorithms; performance, computational complexity, as well as, user dependency. Blotch removal system is an important module of image sequence restoration. In the existing techniques of blotch detection, when generally the high correct detection is necessary, the number of false alarms is also high (JPMB Biemond, van Roosmalen, & Lagendijk, 1999; Ghaderi & Kasaei, 2004). It means that some non-blotch positions are wrongly considered as corrupted parts of image and will be unnecessarily changed later in the restoration process (JPMB Biemond et al., 1999). For this reason, a correct detection rate bigger than 90% and the corresponding false alarms rate less than 1% is desirable for any single frame in different image sequences. In fact, increasing the ratio of correct detection to false alarms is vital action in terms of blotch detection in a blotch removal system (X. Li, Zhang, & Zhang, 2013). Normally, the performance of blotch detection is at risk because of error in motion estimation and noise which is common in old archives. However, any increase in terms of preset threshold in pixel-based methods will reduce the false alarms; consequently, the correct detection also will be reduced in this case as well. Thus, this is not considered a good solution. In addition, many available pixel-based algorithms such as SDIa, ROD need to define some parameters as initial values which show a close interaction of the user and the restoration system to do the image sequence restoration as well (Gullu, Urhan, & Erturk, 2008). In fact, a desirable approach needs a minimum user dependency.

On the other hand, after the detection of the position of blotches, it is vital to restore them (A. C. Kokaram et al., 1995b). Thus, reconstruction of the missing data is another important step after identifying the position of the blotches (Raghunathan, 2004). Interpolation can be organized based on just spatial information, or on spatial and temporal information. Interpolation of the missing data for large area especially in a complex scene is a debatable field of study (A. C. Kokaram, 2004). Reconstruction of large areas based on heuristic approaches does not lead to a reasonable result (A. C. Kokaram, 1993). A large blotch in a complex background will be kept in touch with more edges in different directions. Thus, lack of local characteristics cannot prepare a robust method to reconstruct missing data as much as possible. In fact, there is no guarantee that all blotches in a given frame cause in small sizes, consequently it is desirable to provide a situation to restore defects regardless of their sizes and scene complexity. In the process of restoration the fidelity is very important and every effort in order to handle the procedure of restoration with better quality is appreciated.

In conclusion, design the blotch detection precisely with minimum false alarms, and to restore the missing data regardless of their sizes and the complexity of the scene is desirable. Therefore, design and implement of a blotch removal system in the field of image sequence restoration with better performance in terms of detection and correction can be considered as an interesting field of research.

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1.3 Hypothesis

In order to setup the procedure of blotch removal with high efficiency, the following hypotheses are considered:

1- Pixel-based method can provide the best correct detection while object-based method has the ability to reduce the false alarms. The hypothesis is that devising a method that combines both pixel-based and object-based approaches will lead to higher correct detection and fewer false alarms because of taking the advantages of both methods.

2- The intensities of every single blotch are almost the same. Moreover, their intensities are clearly different from the neighboring pixels. This characteristic of blotches that makes them distinctive and visible in the frame helps to increase the accuracy of blotch detection.

3- Every spot in the frame is part of a bigger homogeneous area that shares features with its surrounding parts. Thus, locally available features of spatial and motion compensated temporal information for a given blotch would enhance the reconstruction of the missing data, regardless of their sizes and complexity.

4- Meta heuristic approaches can efficiently handle many problems because of their abilities to learn and estimate many unknown functions. Therefore, methods based on artificial intelligence techniques would be able to restore the missing data even in a complex scene or a scene with big blotches.

1.4 Research Objectives

This thesis aims to design and implement a new effective blotch removal system having the following sub objectives.

1- To develop an algorithm based on the multi-level scanning and shape analysis in order to achieve good ratio of high correct detection to false alarms in blotch detection.

2- To apply meta-heuristic techniques to develop restoration algorithms. These new algorithms supposed to correct the known missing data refer to blotches positions. They are designed based on genetic algorithm using single and multiple references as well as artificial neural network methods using global and local information. Moreover, spatial and temporal available data are utilized in the correction process. This enables to reconstruct missing data regardless of their sizes and complexity of the scene.

3- To make comprehensive comparisons of different blotch removal systems including, detection and correction. Therefore, pixel-based and object-based techniques are investigated for blotch detection. Furthermore, heuristic and model-based methods are compared with meta-heuristic techniques based on

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only spatial or spatial and temporal information. The aim is to achieve better visual quality objectively and subjectively.

As a result, the scope of this thesis is to design and implement a new blotch removal system with better performance based on multi-level scanning and shape analysis, and meta-heuristic methods.

1.5   Contribution

A successful platform including blotch detection and correction was presented in this study. The proposed blotch detection approach based on multi-level scanning and shape analysis was performed effectively to detect the position of blotches compared to the other available methods. This technique is considered as a semi-automatic method for detection. Therefore, the ratio of correct detection to false alarms showed a significant improvement. In addition, the reconstruction of the missing data based on meta-heuristic methodologies based on Genetic algorithm and Artificial Neural Network provided a better fidelity as well. The corrections were made in two different domains, spatial and spatial-temporal. Consequently, the proposed blotch removal approaches proves to have the potential to be applied to real blotches to restore real old archives.

1.6   Thesis Outline

This thesis was built on five chapters. The first chapter presents some general ideas and the problem statement of the work.

Chapter Two reviews the literature about the existing video restoration systems and investigates the major defects of film and video archives. This chapter presents a comprehensive review on blotch detection approaches and also blotch removal methods. A brief review to motion estimation is also presented.

Chapter Three develops a methodology for detection and removal of blotches in image sequences. In order to detect the position of blotches, a post processing approach is presented. Due to reconstruction of the missing data in image sequences, genetic algorithm and neural network are studied and applied to a variety of benchmark samples of image sequences.

Chapter Four investigates the results of blotch detection and also reconstruction of the missing data in image sequences for different benchmark samples. Proposed methods are compared objectively and subjectively to show their robustness and efficiency.

Chapter Five concludes the main findings and results of the thesis. Moreover, it suggests some recommendations for future works.

REFERENCES

Abdella, M., & Marwala, T. (2005). *Treatment of missing data using neural networks and genetic algorithms.* IEEE International Joint Conference on the Neural Networks, IJCNN'05. Proceeding. 2005

Abreu, E., & Mitra, S. (1995). *A signal-dependent rank ordered mean (SD-ROM) filter-a new approach for removal of impulses from highly corrupted images.* International Conference on the Acoustics, Speech, and Signal, ICASSP-95, Processing 1995.

Addis, M. J., Choi, F., & Miller, A. (2005). Planning the digitisation, storage and access of large scale audiovisual archives.

Ahn, K., Kim, M., Hoque, M. M., & Chae, O. (2015). A Cloud Computing Platform for Automatic Blotch Detection in Large Scale Old Media Archives *Intelligent Information and Database Systems* (pp. 519-528): Springer.

Allen, N., Edge, M., Appleyard, J., Jewitt, T., Horie, C., & Francis, D. (1987). Degradation of historic cellulose triacetate cinematographic film: the vinegar syndrome. *Polymer degradation and stability, 19*(4), 379-387.

Alp, B., Haavisto, P., Jarske, T., Oistamo, K., & Neuvo, Y. A. (1990). *Median-based algorithms for image sequence processing.* Paper presented at the Lausanne-DL tentative.

Ammar-Badri, H., & Benazza-Benyahia, A. (2008). *Wavelet-based blotch detection in old movies.* First Workshops on the Image Processing Theory, Tools and Applications, IPTA 2008.

Ammar-Badri, H., & Benazza-Benyahia, A. (2010). *Wavelet-based blotch detection in old movies exploiting interscale dependency.* 10th International Conference on the Information Sciences Signal Processing and their Applications (ISSPA), 2010.

Ammar-Badri, H., & Benazza-Benyahia, A. (2011). *Improving blotch detection in old films by a preprocessing step based on outlier statistical test.* 19th European Conference on the Signal Processing, 2011.

Ammar-Badri, H., & Benazza-Benyahia, A. (2013). *Improved blotch detection in color old films through a robust preprocessing.* the 21st European Conference on the Signal Processing (EUSIPCO), 2013.

Arce, G. R. (1991). Multistage order statistic filters for image sequence processing. IEEE Transactions on *Signal Processing, 39*(5), 1146-1163.

Arce, G. R., & Malaret, E. (1989). *Motion-preserving ranked-order filters for image sequence processing.* IEEE International Symposium on.the Circuits and Systems, 1989.,

Ardizzone, E., Dindo, H., Mazzola, G., Scriminaci, M., & Vitali, M. (2009). *Multi-directional detection of scratches in digitized images.* Paper presented at the Proceedings of the 17th European Signal Processing Conference (EUSIPCO'09).

Baker, S., Scharstein, D., Lewis, J., Roth, S., Black, M. J., & Szeliski, R. (2011). A database and evaluation methodology for optical flow. *International Journal of Computer Vision, 92*(1), 1-31.

Battiato, S., Gallo, G., & Stanco, F. (2002). A locally adaptive zooming algorithm for digital images. *Image and vision computing, 20*(11), 805-812.

Biemond, J., Looijenga, L., Boekee, D., & Plompen, R. (1987). A pel-recursive Wiener-based displacement estimation algorithm. *Signal Processing, 13*(4), 399-412.

Biemond, J., van Roosmalen, P., & Lagendijk, R. (1999). *Improved blotch detection by postprocessing.* International Conference on the Acoustics, Speech, and Signal Processing, 1999. Proceedings., 1999 IEEE.

Bordwell, D., Thompson, K., & Ashton, J. (1997). *Film art: an introduction* (Vol. 7): McGraw-Hill New York.

Bornard, R., Lecan, E., Laborelli, L., & Chenot, J.-H. (2002). *Missing data correction in still images and image sequences.* international conference on Multimedia the Proceedings of the tenth ACM.

Bovik, A. C. (2010). *Handbook of image and video processing*: Academic Press.

Bruni, V., & Vitulano, D. (2004). A generalized model for scratch detection. *Image Processing, IEEE Transactions on, 13*(1), 44-50.

Burt, P. J., & Adelson, E. H. (1983). The Laplacian pyramid as a compact image code. *Communications, IEEE Transactions on, 31*(4), 532-540.

Cafforio, C., & Rocca, F. (1983). The differential method for image motion estimation *Image Sequence Processing and Dynamic Scene Analysis* (pp. 104-124): Springer.

Cai, J., & David Pan, W. (2012). On fast and accurate block-based motion estimation algorithms using particle swarm optimization. *Information Sciences, 197*, 53-64.

Capel, D., & Zisserman, A. (1998). *Automated mosaicing with super-resolution zoom.* IEEE Computer Society Conference on the Computer Vision and Pattern Recognition, Proceedings. 1998

Cham, T.-J., & Cipolla, R. (1998). *A statistical framework for long-range feature matching in uncalibrated image mosaicing.* IEEE Computer Society

Conference on. the Computer Vision and Pattern Recognition, Proceedings. 1998

Chong, M., Liu, P., Goh, W., & Krishman, D. (1997). *A new spatio-temporal MRF model for the detection of missing data in image sequences.* Paper presented at the Acoustics, Speech, and Signal Processing, 1997. ICASSP-97., 1997 IEEE International Conference on.

Corrigan, D., & Kokaram, A. (2004). *Automated treatment of film tear in degraded archived media.* International Conference on the Image Processing, 2004. ICIP'04. 2004.

Dennis, T. (1980). *Nonlinear temporal filter for television picture noise reduction.* Paper presented at the IEE Proceedings G (Electronic Circuits and Systems).

Design, V. C. (2002). Motion Estimation and Compensation.

Dong, G., An, X., & Hu, D. (2013). Horn-Schunck optical flow equations. *Part I: Stability and Rate of Convergence of the Classical Algorithm (accepted by Journal of Central South University, under minor modification)*.

Dubois, E., & Sabri, S. (1984). Noise reduction in image sequences using motion-compensated temporal filtering. IEEE Transactions on *Communications, 32*(7), 826-831.

Dufaux, F., & Moscheni, F. (1995). Motion estimation techniques for digital TV: A review and a new contribution. *Proceedings of the IEEE, 83*(6), 858-876.

Efstratiadis, S., & Katsaggelos, A. (1990). *A model-based pel-recursive motion estimation algorithm.* International Conference on the Acoustics, Speech, and Signal Processing, 1990. ICASSP-90.

Elmer, L. A., & Shea, T. E. (1936). Motion picture film: US Patent 2,048,497.

Engler, A., Grass, M., Movassaghi, B., Rasche, V., & Schaefer, D. (2007). Hierarchical motion estimation: Google Patents.

Enkelmann, W. (1988). Investigations of multigrid algorithms for the estimation of optical flow fields in image sequences. *Computer Vision, Graphics, and Image Processing, 43*(2), 150-177.

Estrela, V. V., & Bassani, M. H. d. S. (2014). Expectation-Maximization Technique and Spatial-Adaptation Applied to Pel-Recursive Motion Estimation. *arXiv preprint arXiv:1403.7365*.

Falkenhagen, L. (1997). *Hierarchical block-based disparity estimation considering neighbourhood constraints.* Paper presented at the Proc. International Workshop on SNHC and 3D Imaging.

Fogel, L. J., Owens, A. J., & Walsh, M. J. (1966). Artificial intelligence through simulated evolution.

Geman, S., & Geman, D. (1984). Stochastic relaxation, Gibbs distributions, and the Bayesian restoration of images. IEEE Transactions on(*Pattern Analysis and Machine Intelligence, (*6), 721-741.

Ghaderi, M., & Kasaei, S. (2004). Novel post-processing methods used in detection of blotches in image sequences. *AEU-International Journal of Electronics and Communications, 58*(1), 58-64.

Goldstein, T., & Osher, S. (2009). The split Bregman method for L1-regularized problems. *SIAM Journal on Imaging Sciences, 2*(2), 323-343.

Gullu, M. K., Urhan, O., & Erturk, S. (2008). Blotch detection and removal for archive film restoration. *AEU-International Journal of Electronics and Communications, 62*(7), 534-543.

Hagan, M. T., Demuth, H. B., & Beale, M. H. (1996). *Neural network design*: Pws Pub. Boston.

Han, Y., & Li, N. (2010). *Interpolation of missing hydrological data based on BP-Neural Networks.* 2nd International Conference on the Information Science and Engineering (ICISE), 2010.

Harvey, N., & Marshall, S. (1997). *Application of non-linear image processing: digital video archive restoration.* International Conference on the Image Processing,.

Haskell, B. G. (1974). Frame-to-frame coding of television pictures using two-dimensional Fourier transforms (Corresp.). IEEE Transactions on *Information Theory, 20*(1), 119-120.

Haykin, S. (1994). *Neural networks: a comprehensive foundation*: Prentice Hall PTR.

Hiriyannaiah, H. P., Bilbro, G. L., Snyder, W. E., & Mann, R. C. (1989). Restoration of piecewise-constant images by mean-field annealing. *JOSA A, 6*(12), 1901-1912.

Hou, H. S., & Andrews, H. (1978). Cubic splines for image interpolation and digital filtering. IEEE Transactions on *Acoustics, Speech and Signal Processing, 26*(6), 508-517.

Huang, T., & Tsai, R. (1981). Image sequence analysis: Motion estimation *Image Sequence Analysis* (pp. 1-18): Springer.

Huo, X., Tan, J., He, L., & Hu, M. (2013). An automatic video scratch removal based on Thiele type continued fraction. *Multimedia Tools and Applications*, 1-17.

Isgrò, F., & Tegolo, D. (2008). A distributed genetic algorithm for restoration of vertical line scratches. *Parallel Computing, 34*(12), 727-734.

104

Jackson, S., & Sovakis, A. (2005). *Adaptive multilevel median filtering of image sequences.* IEEE International Conference on. the Image Processing, 2005. ICIP 2005.

Jain, A. K. (1989). *Fundamentals of digital image processing*: Prentice-Hall, Inc.

Jakubowski, M., & Pastuszak, G. (2013). Block-based motion estimation algorithms—a survey. *Opto-Electronics Review, 21*(1), 86-102.

Japkowicz, N. (2001). Supervised versus unsupervised binary-learning by feedforward neural networks. *Machine Learning, 42*(1-2), 97-122.

Ji, H., Shen, Z., & Xu, Y. (2011). Wavelet frame based image restoration with missing/damaged pixels. *East Asia Journal on Applied Mathematics, 1*(2), 108-131.

Joyeux, L., Buisson, O., Besserer, B., & Boukir, S. (1999). *Detection and removal of line scratches in motion picture films.* Paper presented at the 2013 IEEE Conference on Computer Vision and Pattern Recognition.

Kaprykowsky, H., Liu, M., & Ndjiki-Nya, P. (2009). *Restoration of digitized video sequences: an efficient drop-out detection and removal framework.* 16th IEEE International Conference on. the Image Processing (ICIP), 2009

Katsaggelos, A. K. (2012). *Digital image restoration*: Springer Publishing Company, Incorporated.

Kazlauskas, K., & Pupeikis, R. (2014). Missing data restoration algorithm. *INFORMATICA, 25*(2), 209-220.

Keller, U. (2013). *The building of the Panama Canal in historic photographs*: Courier Dover Publications.

Kim, B., Kim, K.-t., & Kim, E. Y. (2009). *Reconstruction of degraded images using genetic algoritm for archive film restoration.* 16th IEEE International Conference on the Image Processing (ICIP), 2009.

Kim, K.-t., Kim, B., & Kim, E. Y. (2010). *Automatic restoration of scratch in old archive.* 20th International Conference on. the Pattern Recognition (ICPR), 2010

Kim, K.-t., & Kim, E. Y. (2008). *Film line scratch detection using neural network and morphological filter.* IEEE Conference on the Cybernetics and Intelligent Systems, 2008.

Koc, U.-V., & Liu, K. R. (1994). *Discrete-cosine/sine-transform based motion estimation.* IEEE International Conference the Image Processing, 1994. Proceedings. ICIP-94.

Kokaram, A., Bornard, R., Rares, A., Sidorov, D., Chenot, J.-H., Laborelli, L., & Biemond, J. (2002). *Robust and automatic digital restoration systems: coping with reality.* Paper presented at the Proc. Int. Broadcasting Convention.

Kokaram, A. C. (1993). *Motion picture restoration.* Citeseer.

Kokaram, A. C. (1998). Line Registration for Jittered Video *Motion Picture Restoration* (pp. 99-118): Springer.

Kokaram, A. C. (1999). *Removal of line artefacts for digital dissemination of archived film and video.* IEEE International Conference on the Multimedia Computing and Systems, 1999.

Kokaram, A. C. (2001). Advances in the detection and reconstruction of blotches in archived film and video.

Kokaram, A. C. (2004). On missing data treatment for degraded video and film archives: a survey and a new Bayesian approach. IEEE Transactions on *Image Processing, 13*(3), 397-415.

Kokaram, A. C., & Godsill, S. J. (1996). A system for reconstruction of missing data in image sequences using sampled 3D AR models and MRF motion priors *Computer Vision—ECCV'96* (pp. 613-624): Springer.

Kokaram, A. C., Morris, R. D., Fitzgerald, W. J., & Rayner, P. J. (1995a). Detection of missing data in image sequences. IEEE Transactions on *Image Processing, 4*(11), 1496-1508.

Kokaram, A. C., Morris, R. D., Fitzgerald, W. J., & Rayner, P. J. (1995b). Interpolation of missing data in image sequences. IEEE Transactions on *Image Processing, 4*(11), 1509-1519.

Kokaram, A. C., & Rayner, P. J. (1992). *System for the removal of impulsive noise in image sequences.* Paper presented at the Applications in Optical Science and Engineering.

Kosko, B. (1992). *Neural Networks and Fuzzy Systems: A Dynamical Systems Approach to Machine Intelligence/Book and Disk* (Vol. 1): Prentice hall.

Kozlov, I., Petukhov, A., & Zheludev, V. (2010). Automatic digital film and video restoration: Google Patents.

Li, H., Lu, Z., Wang, Z., Ling, Q., & Li, W. (2013). Detection of Blotch and Scratch in Video Based on Video Decomposition.

Li, S. Z. (1995). *Markov random field modeling in computer vision*: Springer-Verlag New York, Inc.

Li, S. Z., & Singh, S. (2009). *Markov random field modeling in image analysis* (Vol. 26): Springer.

Li, X., Zhang, R., & Zhang, Y. (2013). *The detection of blotches in old movies.* Paper presented at the Signal and Information Processing Association Annual Summit and Conference (APSIPA), 2013 Asia-Pacific.

Lim, J. S. (1990). Two-dimensional signal and image processing. *Englewood Cliffs, NJ, Prentice Hall, 1990, 710 p., 1*.

Malfait, M., & Roose, D. (1997). Wavelet-based image denoising using a Markov random field a priori model. IEEE Transactions on *Image Processing, 6*(4), 549-565.

Mann, N. R., Schafer, R. E., & Singpurwalla, N. D. (1974). *Methods for statistical analysis of reliability and life data* (Vol. 15): Wiley New York.

Marhaban, M. H., Jabir, A. N., & Noor, S. B. M. (2008). Modified minimum-maximum exclusive mean filter. *IEICE Electronics Express, 5*(20), 865-869.

Martinez, D. M. (1987). Model-based motion estimation and its application to restoration and interpolation of motion pictures. *NASA STI/Recon Technical Report N, 88*, 13558.

Matsushita, Y., Ofek, E., Ge, W., Tang, X., & Shum, H.-Y. (2006). Full-frame video stabilization with motion inpainting. IEEE Transactions on *Pattern Analysis and Machine Intelligence, 28*(7), 1150-1163.

McCulloch, W. S., & Pitts, W. (1943). A logical calculus of the ideas immanent in nervous activity. *The bulletin of mathematical biophysics, 5*(4), 115-133.

Messina, A., Boch, L., Dimino, G., Bailer, W., Schallauer, P., Allasia, W., . . . Basili, R. (2006). *Creating rich metadata in the TV broadcast archives environment: The Prestospace project.* Second International Conference on the Automated Production of Cross Media Content for Multi-Channel Distribution, 2006. AXMEDIS'06.

Modestino, J. W., & Zhang, J. (1989). *A Markov random field model-based approach to image interpretation.* IEEE Computer Society Conference on the Computer Vision and Pattern Recognition, 1989. Proceedings CVPR'89.

Morris, R. D., Fitzgerald, W., & Kokaram, A. (1996). *A sampling based approach to line scratch removal from motion picture frames.* International Conference on the Image Processing, 1996. Proceedings.

Morris, R. D., Fitzgerald, W. J., & Kokaram, A. C. (1996). *A sampling based approach to line scratch removal from motion picture frames.* International Conference on the Image Processing, 1996. Proceedings.

Muralidhar[1], P., Rao, C. R., & Kumar, I. R. (2012). Efficient architecture for variable block size motion estimation of h. 264 video encoder.

Nam, S.-C., Abe, M., & Kawamata, M. (2007). *Fast blotch detection algorithm for degraded film sequences based on MRF models.* IEEE International Conference on the Image Processing, 2007. ICIP 2007.

Nelson, M. S., Wooditch, A., & Dario, L. M. (2015). Sample size, effect size, and statistical power: a replication study of Weisburd's paradox. *Journal of Experimental Criminology, 11*(1), 141-163.

Nelwamondo, F. V., Golding, D., & Marwala, T. (2013). A dynamic programming approach to missing data estimation using neural networks. *Information Sciences, 237*, 49-58.

Netravali, A. N., & Robbins, J. (1979). Motion-Compensated Television Coding: Part I. *Bell System Technical Journal, 58*(3), 631-670.

Nieminen, A., Heinonen, P., & Neuvo, Y. (1987). A new class of detail-preserving filters for image processing. IEEE Transactions on *Pattern Analysis and Machine Intelligence,* (1), 74-90.

Ott, H. W., & Ott, H. W. (1988). *Noise reduction techniques in electronic systems*: Wiley New York.

Panjwani, D. K., & Healey, G. (1995). Markov random field models for unsupervised segmentation of textured color images. IEEE Transactions on *Pattern Analysis and Machine Intelligence, 17*(10), 939-954.

Park, H.-W., & Kim, H.-S. (2000). Motion estimation using low-band-shift method for wavelet-based moving-picture coding. IEEE Transactions on *Image Processing, 9*(4), 577-587.

Parker, J. R. (2010). *Algorithms for image processing and computer vision*: John Wiley & Sons.

Pitié, F., Dahyot, R., Kelly, F., & Kokaram, A. (2004). A new robust technique for stabilizing brightness fluctuations in image sequences *Statistical Methods in Video Processing* (pp. 153-164): Springer.

Raghunathan, T. E. (2004). What do we do with missing data? Some options for analysis of incomplete data. *Annu. Rev. Public Health, 25*, 99-117.

Ram, A. T., Kopperl, D. F., Sehlin, R. C., Morris, S. M. K., Vincent, J. L., & Miller, P. (1994). The Effects and Prevention of the. *Journal of Imaging Science and Technology, 38*(3), 249-261.

Rares, A., Reinders, M., & Biemond, J. (2001). Statistical analysis of pathological motion areas.

Rechenberg, I. (1965). Cybernetic solution path of an experimental problem.

Reed, A. M., & Rhoads, G. B. (2012). Color image or video processing: Google Patents.

Reed, T. R. (2004). *Digital Image Sequence Processing, Compression, and Analysis* (Vol. 2): CRC Press.

Schafer, J. L., & Graham, J. W. (2002). Missing data: our view of the state of the art. *Psychological methods, 7*(2), 147.

Schallauer, P., Bailer, W., Morzinger, R., Furntratt, H., & Thallinger, G. (2007). *Automatic quality analysis for film and video restoration.* IEEE International Conference on the Image Processing, 2007. ICIP 2007.

Schallauer, P., Pinz, A., & Haas, W. (1999). Automatic restoration algorithms for 35mm film. *J. Computer Vision Res, 1*(3), 59-85.

Schattschneider, E. (2012). Film and Video. *General Anthropology, 19*(1), 14-15.

Schwefel, H.-P. (1975). *Evolutionsstrategie und numerische Optimierung.* Technische Universität Berlin.

Smith, P., Balio, T., McConathy, D., Vreeland, D., Chierichetti, D., Slide, A., . . . Braudy, L. (1976). Motion Picture History.

Sonka, M., Hlavac, V., & Boyle, R. (2014). *Image processing, analysis, and machine vision*: Cengage Learning.

Specht, D. F. (1990). Probabilistic neural networks. *Neural networks, 3*(1), 109-118.

Stiller, C. (1990). *Motion estimation for coding of moving video at 8 kbit/s with Gibbs-modeled vectorfield smoothing*. Paper presented at the Lausanne-DL tentative.

Storey, R. (1985). Electronic detection and concealment of film dirt. *SMPTE journal, 94*(6), 642-647.

Suh, J. W., & Jeong, J. (2004). Fast sub-pixel motion estimation techniques having lower computational complexity. IEEE Transactions on *Consumer Electronics, 50*(3), 968-973.

Svozil, D., Kvasnicka, V., & Pospichal, J. í. (1997). Introduction to multi-layer feed-forward neural networks. *Chemometrics and intelligent laboratory systems, 39*(1), 43-62.

Tegolo, D., & Isgro, F. (2001). *Scratch detection and removal from static images using simple statistics and genetic algorithms.* International Conference on the Image Processing, 2001. Proceedings. 2001.

Thompson, J. B. (2013). *Media and modernity: A social theory of the media*: John Wiley & Sons.

Thompson, W. B., Mutch, K. M., & Berzins, V. A. (1985). Dynamic occlusion analysis in optical flow fields. IEEE Transactions on *Pattern Analysis and Machine Intelligence,* (4), 374-383.

Tilie, S., Laborelli, L., & Bloch, I. (2006). *Blotch detection for digital archives restoration based on the fusion of spatial and temporal detectors.* 9th International Conference on.the Information Fusion, 2006

Todorovic, A. L. (2006). *Television Technology Demystified*: Elsevier.

Tukey, J. W. (1977). Exploratory data analysis.

Van Roosmalen, P. M., Westen, S., Lagendijk, R. L., & Biemond, J. (1996). *Noise reduction for image sequences using an oriented pyramid thresholding technique.* International Conference on the Image Processing, 1996. Proceedings.

van Roosmalen, P. M. B. (1999). *Restoration of archived film and video*: Universal Press.

Vani, R., Davis, P., & Sangeetha, M. (2014). Modified Cross Hexagon Diamond Search Algorithm for Fast Block Matching Motion Estimation. *International Journal of Engineering & Technology (0975-4024), 6*(4).

Vaseghi, S. V. (1988). *Algorithms for restoration of archived gramophone recordings.* University of Cambridge.

Verhoeven, D. (2006). Film and video. *The Media and Communications in Australia, 2*, 154-174.

Vlachos, T. (2004). Flicker correction for archived film sequences using a nonlinear model. IEEE Transactions on the *Circuits and Systems for Video Technology, 14*(4), 508-516.

Vlachos, T., & Thomas, G. (1996). *Motion estimation for the correction of twin-lens telecine flicker.* International Conference on. the Image Processing, 1996. Proceedings.

Wadhwa, N., Rubinstein, M., Durand, F., & Freeman, W. T. (2013). Phase-based video motion processing. *ACM Transactions on Graphics (TOG), 32*(4), 80.

Wei, S., Zhang, R., Hao, P., & Ding, Y. (2009). *Blotch detection based on texture matching and adaptive multi-threshold.* Fifth International Conference on the Image and Graphics, 2009. ICIG'09.

Weickert, J., Bruhn, A., & Schnörr, C. (2011). Lucas/Kanade meets Horn/Schunck: Combining local and global optic flow methods.

Xu, L., Jia, J., & Matsushita, Y. (2012). Motion detail preserving optical flow estimation. IEEE Transactions on *Pattern Analysis and Machine Intelligence, , 34*(9), 1744-1757.

Xu, Z., Wu, H. R., Yu, X., & Qiu, B. (2014). Features based spatial and temporal blotch detection for archive video restoration. *Journal of Signal Processing Systems*, 1-14.

Yang, X., & Toh, P. S. (1994). Adaptive fuzzy multilevel median filter. *IEEE transactions on image processing: a publication of the IEEE Signal Processing Society, 4*(5), 680-682.

Zhang, J. (1995). The application of the Gibbs-Bogoliubov-Feynman inequality in mean field calculations for Markov random fields. *IEEE transactions on image processing: a publication of the IEEE Signal Processing Society, 5*(7), 1208-1214.

Zhang, R., Wu, J., Ding, Y., & Hao, P. (2009). *The Correction of Intensity Flicker in Archived Film.* International Conference on the Information Technology and Computer Science, 2009. ITCS 2009.

Zoghlami, I., Faugeras, O., & Deriche, R. (1997). *Using geometric corners to build a 2D mosaic from a set of images.* IEEE Computer Society Conference on. the Computer Vision and Pattern Recognition, Proceedings., 1997