Colour Consistency in Computer Vision:
A Multiple Image Dynamic Exposure Colour Classification System

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Abstract

Colour classification vision systems face difficulty when a scene contains both very bright and dark regions. An indistinguishable colour at one exposure may be distinguishable at another. The use of multiple cameras with varying levels of sensitivity is explored in this thesis, aiding the classification of colours in scenes with high illumination ranges. Titled the Multiple Image Dynamic Exposure Colour Classification (MIDECC) System, pie-slice classifiers are optimised for normalised red/green and cyan/magenta colour spaces. The MIDECC system finds a limited section of hyperspace for each classifier, resulting in a process which requires minimal manual input with the ability to filter background samples without specialised training. In experimental implementation, automatic multiple-camera exposure, data sampling, training and colour space evaluation to recognise 8 target colours across 14 different lighting scenarios is processed in approximately 30 seconds. The system provides computationally effective training and classification, outputting an overall true positive score of 92.4% with an illumination range between bright and dim regions of 880 lux. False positive classifications are minimised to 4.24%, assisted by heuristic background filtering. The limited search space classifiers and layout of the colour spaces ensures the MIDECC system is less likely to classify dissimilar colours, requiring a certain 'confidence' level before a match is outputted. Unfortunately the system struggles to classify colours under extremely bright illumination due to the simplistic classification building technique. Results are compared to the common machine learning algorithms Naïve Bayes, Neural Networks, Random Tree and C4.5 Tree Classifiers. These algorithms return greater than 98.5% true positives and less than 1.53% false positives, with Random Tree and Naïve Bayes providing the best and worst comparable algorithms, respectively. Although resulting in a lower classification rate, the MIDECC system trains with minimal user input, ignores background and untrained samples when classifying and trains faster than most of the studied machine learning algorithms.

Chapter 1

1. Research Description

Reliably classifying colours in a computer vision system is a difficult and often computationally expensive task. In comparison, the human vision system is well apt at both detecting subtle differences in similar colours and recognising the same colour when subject to varying illuminations.

1.1 Overview of the Current State of Technology

Current implementations of colour classifiers, such as Fuzzy Colour Contrast Fusion (FCCF) successfully compensate for limited illumination variation, searching a pie-slice decision region using colour contrast rules to strengthen or weaken matches to a particular colour classification [1]. FCCF requires the user to manually calibrate each colour into a pie-slice decision region, before using a brute-force method to choose contrast operations to run on the incoming red, green and blue channels. It will be imperative to this research to automate as much of the classifier generation as possible, while assessing if FCCF is a valid addition to the processing pipeline.

A current implementation of automatic exposure practices histogram matching to compare a stored reference value with the current input image [2]. While this method is robust enough to be run in real time, this research will focus on the use of no external reference points, minimising human interaction once the training process has begun.

Other research has been conducted into which the background of a scanned text document is removed, emphasising the typescript and images later to be scanned by an Optical Character Recognition (OCR) program [3]. The various steps to the overall process and use of a standardised 'Ostu's method' of binary thresholding will be amongst the techniques used to reduce processing time for this research paper.

Different approaches have been reviewed regarding multiple camera inputs, with one paper suggesting the distribution of computational processing throughout the network, reducing camera system traffic [4]. Reducing the amount of processing by only running the minimum required on a 'slave' camera is also studied [5], while another paper highlighting the difficulties in multiple camera alignment and processing [6].

1.2 Research Objectives

1.2.1 General Objective

To develop a robust and efficient automatic colour classification system which assesses multiple frames taken simultaneously from three different cameras. Each camera is to have a distinct exposure setting, widening the dynamic range captured.
The system will endeavour to find an optimal classifier, providing robust results when classifying colours in as many bright and dim lighting scenarios as possible.

1.2.2 Specific Objectives

1. To investigate how three input images may be combined to provide select regions where each specialises in a particular exposure range for the explicit task of colour recognition.
2. To investigate the reduction of ambiguity by prioritising matches when multiple classifiers do not return a unanimous result.
3. To investigate the use of a novel colour space, 'normalised cyan/magenta' to complement the strengths of the normalised red/green colour space using a pie-slice classifier.
4. To investigate background image removal without reducing the accuracy of colour classification.
5. To investigate the feasibility of implementing FCCF to strengthen classification results.

1.3 Significance of Research

This research employs multiple sub-processes to create a simple multiple image colour classification system:

- A unique colour space is introduced, complementary to previous research to aid the classification in difficult illumination (Section 4.2)
- An automatic exposure process calibrates each camera exposure, resulting in each camera specialising in a particular brightness region (Section 4.3.3)
- Colour classifiers are spread amongst two colour spaces, extending the feature classification range while using only the 'preferred' space, reducing processing time (Section 4.5.2)
- A simple, yet effective method of prioritising classifiers is used if multiple classifiers match, providing reliable output (Section 4.5.4)

The MIDECC system trains in a supervised learning environment, faster than three of the four common machine learning algorithms discussed in Section 2.6. Once the data is collected for each colour, assuming a normal distribution quickly calculates a pie slice classifier, discussed in Section 4.5.1.

1.4 Scope and Limitations of Research

This research is limited to the colours definable in the normalised red/green colour space. Due to the layout of the colour space, this excludes colours such as white, grey and black.

It is assumed that the colour patches are a matte finish and are an acceptable size to be recognised by the camera at a reasonable distance. It is also assumed that the lighting of the testing environment is relatively free of colour cast or shadows that may disrupt the training process.

Much of the proposed system will be automated, however some values may require manual fine-tuning. Manual parameters to be provided are the sampling of colours for the exposure selection process (Section 4.3.3) and the threshold at which colours are classified as background pixels (Section 4.6). Setting these parameters do not require specialist knowledge of the system, as settings will be easily accessible and their actions immediately observable in the system output.

The system will be tested to classify illumination varying from 175 lux to 11,230 lux. It is expected that the system may struggle at these extremities, however limitations and evaluated ranges will be discussed, concluding this thesis.

1.5 Structure of Thesis

This thesis begins in Chapter 2 by covering concepts such as colour, image adjustments such as contrast and sharpness, geometric transforms and the use of Fuzzy Logic. Introductions to the comparison classifiers are given to provide a background to the standardised testing the system is evaluated against in Section 2.6.

Previous research is discussed in Chapter 3, exploring papers which focus on colour classification, image contrast adjustment, image exposure selection and multiple image processing.

A complementary colour space, the Normalised Cyan/Magenta chromaticity is introduced in Section 4.2, along with the system process for exposure selection, colour classification, and evaluation in the remainder of Chapter 4. These processes combine, creating the MIDECC system, implemented Chapter 5. Results will be discussed in Chapter 6 and conclusions drawn in Chapter 7.

Chapter 7

7. Conclusions

The Multiple Image Dynamic Exposure Colour Classification (MIDECC) System was developed in an effort to provide reliable colour classification for a scene with extreme variations in lighting conditions.

Development of different sub-systems which pre-process multiple camera images (Section 4.3), remove background samples (Section 4.6) and score unique colour space models (Section 4.5.2) result in a robust system which requires minimal user training parameters. The MIDECC System is quick to train, with the majority of time spent averaging samples or waiting for external camera inputs to stabilise.

Drawing on previous research into a unique classifier [19] and normalised red/green chromaticity [1], a novel complementary cyan/magenta chromaticity is proposed which further assists the system by providing a greater separation between individual classifiers, grouping certain colours together while separating others.

The MIDECC System does not require retraining for a data set that includes background samples, as the background removal process largely deals with the eradication of false positives, while keeping the true positive rate the same as without background input.

When different input images match dissimilar classifiers, a simple normal density function is assessed in the preferred classifiers' colour space. This provides a relatively quick and reliable way of prioritising matches, resulting in a single classifier output.

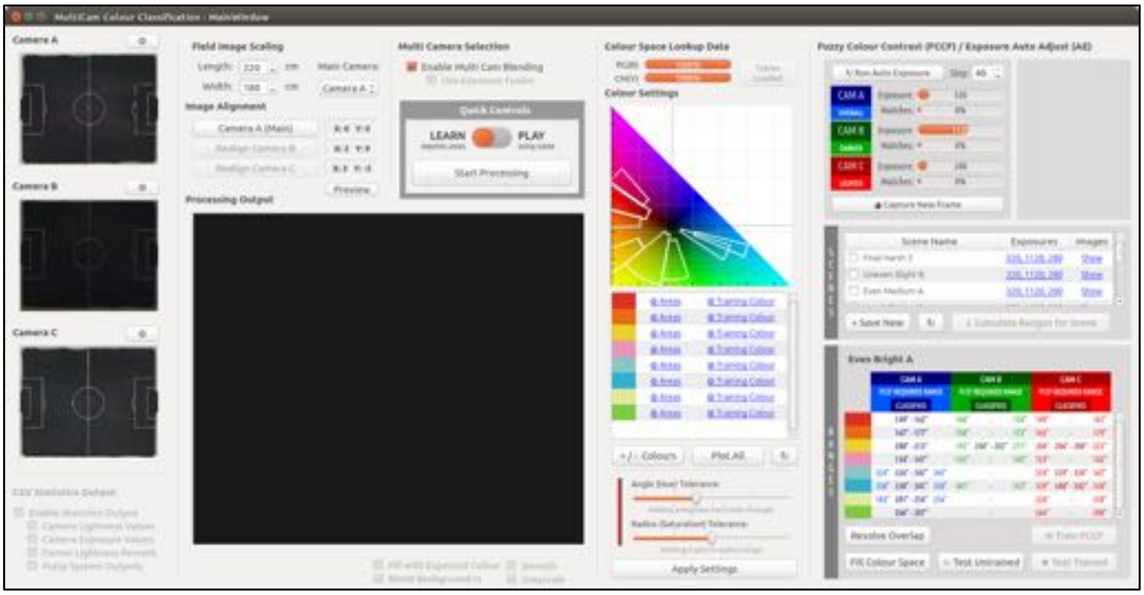
The results of experiments herald a 92.46% true positive rate, while minimising false positives to 4.25%. The system has been observed to reliably classify colours in illumination ranging from 210 lux to 1,097 lux in the same frame.

The lower illumination limit of 210 lux is equivalent to two standard fluorescent tubes at a height of 3 meters illuminating a room totally occluded from sunlight, while the upper limit of 1,097 lux is comparable 14 standard fluorescent tubes and 4 halogen spotlights illuminating the room at the same height.

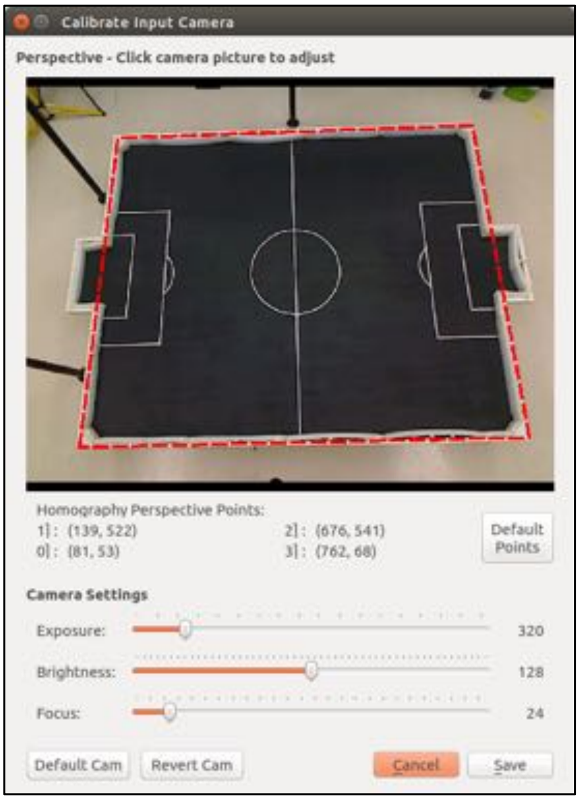
Appendix A: Experiment Implementation

The MIDECC System was implemented in C++ in the Qt IDE, allowing rich GUI functionality. Additional libraries were also used, listed below.

Software	Version	Use in MIDECC System
Qt IDE www.qt.io	5.2.1 GCC 4.8.2 64-bit	• C++ Framework • User Interface & Window Management • File I/O • Multithreading • Painting output graphics
OpenCV www.opencv.org	3.0	• Camera Image Input • Homography Processing • Image Pre-processing
QCustomPlot www.qcustomplot.com	1.3.1	• Colour space graphics & plot display
Video4Linux linuxtv.org	2.0	• Camera command

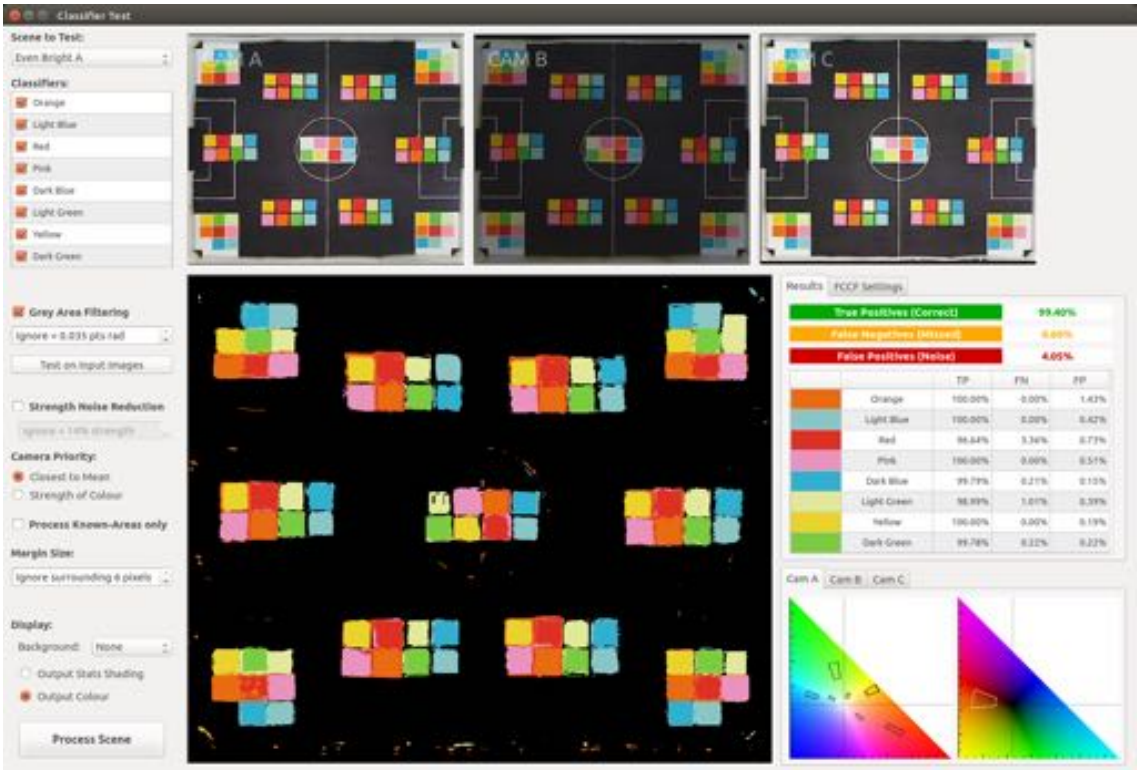


This program facilitates the image pre-processing by manually selected homographic points, scales image based on the real-life measurements entered, then automatically aligns each camera. The exposure selection process is run using the defined colours and areas, before allowing lighting scenarios to be saved to file.



Camera C, shown above, ready for alignment. The homographic points, generated by clicking on the live image, are shown as a red dotted rectangle.

The next program loads the PNG image files and known-areas, plotting data to the two colour spaces. Testing then prioritises one over the other, before saving the classifier to file. As mentioned in Section 4.5, 24 classifiers are saved in total.



This final program loads each classifier from file, along with a particular lighting scenario. Outputs such as confusion matrices, true positives and false positives are generated here for each scene, saved directly to CSV file for further analysis.

Appendix B: Visual MIDDEC System Results

The pages following list all of the results for the MIDECC system, showing inputs and outputs for corresponding lighting scenarios.