ENHANCED SKIN COLOUR CLASSIFIERS USING PIXEL-BASED AND REGION-BASED MODELLING TECHNIQUES

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DEDICATION

Dedicated to my loving wife, my children, all members of the family, and all friends those fully support my study.

ABSTRACT

Abstract of the thesis presented to the Senate of Universiti Malaysia Terengganu in fulfilment of the requirement for the degree of Doctor of Philosophy

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Skin colour detection is frequently been used for searching people, face detection, pornographic filtering and hand tracking. Skin colour detection is a process to determine whether a desired pixel or a group of pixels belongs to skin or non-skin. The presence of skin or non-skin in digital image can be determined by manipulating pixels' colour and/or pixels' texture. For still image, skin colour detection is a task where an image is produced as input to the process and its output is a set of positions of skin pixels or non-skin pixels. The process of skin detection involves classification technique, which is carried out at an individual pixel or a group of pixels. Thus, skin classification technique can be categorised into two categories; pixel-based and region-based classification techniques.

The main challenge of skin colour detection is to develop a classifier that is robust to the large variations in skin colour appearance. This process is difficult because the appearance of a skin colour in an image depends on the illumination conditions where the image was captured. Therefore, the main problem in skin colour detection is to represent the skin colour distribution model that is invariant or least sensitive to changes in illumination condition. Another problem comes from the fact that many objects in the real world may possess almost similar skin-tone colour such as wood, leather, skin-coloured clothing, hair and sand. Moreover, skin colour is different between races and can be different from a person to another, even with people of the same ethnicity. Finally, skin colour will appear a little different when different types of camera are used to capture the object or scene.

The objective in this thesis is to develop a skin colour classifiers based on two classification techniques; pixel-based and region-based, by using an explicitly defined skin region, parametric-based, and non-parametric-based methods. These skin classifiers were tested with SIdb dataset and two benchmark datasets; UChile and TDSD datasets to measure classifier performance. The performance of skin classifier was measured based on true positive (TF) and false positive (FP) indicator.

In pixel-based classification technique, there are three methods have been carried out to model skin colour distribution; RGB ratio, linear discriminant analysis (LDA) and back propagation neural network (NN). The RGB ratio model represents an explicitly defined skin region method while LDA and NN represent parametric and non-parametric methods, respectively. The RGB ratio model is a newly proposed method that belongs under the category of an explicitly defined skin region model.

This newly proposed model was compared with Kovac, Saleh and Swift models. The experimental results showed that the RGB ratio model outperformed all the other models in term of detection rate. The RGB ratio model is able to reduce FP detection that caused by reddish objects colour as well as be able to detect darkened skin and skin covered by shadow. Meanwhile, the experiment to develop skin colour distribution model were also conducted by using LDA and NN methods with eight colour models; RGB, HSV, YIQ, YCbCr, LUX, *Opponent*, CIE-Lab and RGB normalised colour models. The experimental results showed that all colour models performed better when developed using NN method as compared to LDA except for LUX colour model. The experimental results also showed that the CIE-Lab colour model performed better in both NN and LDA methods in developing skin classifier.

In region-based classification technique, thirteen Haralick texture features were used to develop skin colour distribution model. A new technique to compute Haralick's texture features for skin colour classification is introduced in this thesis, which is called as colour mapping co-occurrence matrix (CMCM). There are four CMCMs were developed at difference colour mapping; [RGB], [RG], [RB], and [GB] CMCMs. There are also three modelling techniques were carried out in this classification technique; an explicitly defined skin region, LDA, and NN. The homogeneity property threshold model is introduced in explicitly defined skin region method. This model produced high performance in terms of FP rate.

The LDA and NN methods were applied with CMCM method to develop skin classifier. There were four CMCMs used in this experiment; [RGB] CMCM at direction (1, 0^{o}), (1, 45^{o}), (1, 90^{o}) and (1, 135^{o}), [RG], [RB] and [GB] CMCMs at

direction (1, 0^{o}), (1, 45^{o}). The experimental results showed that skin classifier derived with colour mapping [RGB] CMCM at direction (1, 0^{o}) outperformed CMCM at other directions in terms of FP rate. These experimental results also showed that the skin classifier derived with colour mapping [RGB] CMCM at direction (1, 90^{o}) is unable to detect skin and non-skin pixels. Meanwhile, the skin classifier derived with colour mapping [RG] CMCM at direction (1, 0^{o}) outperformed colour mapping [RB] CMCM and colour mapping [GB] CMCMs at direction (1, 0^{o}) and (1, 45^{o}), respectively in terms of FP rate, and its performance was not significantly different with [RGB] CMCM at direction (1, 0^{o}). In conclusion, the experimental results showed that the skin classifier derived using NN method produced better result as compared to LDA method.

ABSTRAK

Abstrak tesis ini dikemukakan kepada Senat Universiti Malaysia Terengganu sebagai memenuhi keperluan untuk Ijazah Kedoktoran Falsafah

PENAMBAHBAIKAN PENGKELAS WARNA KULIT MENGGUNAKAN TEKNIK PERMODELAN BERASASKAN PIKSEL DAN RANTAU

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Pengesanan warna kulit kerap digunakan sebagai fetur bagi mencari manusia, mengesan muka, menapis bahan lucah dan menjejak tangan. Pengesanan warna kulit adalah proses bagi menentukan sama ada sesuatu piksel atau kelompok piksel merupakan warna kulit atau warna bukan-kulit. Kewujudan kulit atau bukan-kulit pada imej digital boleh ditentukan dengan memanipulasi warna piksel atau tekstur pixel. Bagi imej pegun, pengesanan warna kulit adalah satu tugas di mana imej menghasilkan input untuk diproses dan hasilnya adalah satu set lokasi piksel kulit atau piksel bukan-kulit. Proses pengesanan melibatkan pendekatan klasifikasi yang dilakukan secara individual piksel atau secara satu kelompok piksel. Oleh itu,

pendekatan klasifikasi kulit boleh dikategorikan kepada dua; pendekatan klasifikasi berasaskan piksel dan pendekatan klasifikasi berasaskan rantau.

Cabaran utama dalam pengesanan warna kulit adalah bagi membangunkan pengkelas yang berupaya mengesan kulit dalam berbagai warna kulit. Ini kerana kemunculan warna kulit pada imej digital bergantung kepada keadaan iluminasi lokasi imej diambil. Oleh itu, masalah utama dalam pengesanan warna kulit adalah untuk membangunkan model taburan warna kulit yang tidak atau kurang sensitif kepada perubahan keadaan iluminasi persekitaran. Manakala masalah lainnya, kebanyakan objek di persekitaran mempunyai warna yang hampir sama dengan warna kulit seperti kayu, kulit haiwan, pakaian, rambut, dan pasir. Selain daripada itu, warna kulit juga boleh berbeza antara individul meskipun dalam kelompok bangsa yang sama. Akhir sekali, warna kulit akan nampak sedikit berbeza bila mana menggunakan kamera yang berbeza untuk mengambil gambar.

Objektif tesis ini adalah untuk membangunkan satu model taburan warna kulit berasaskan dua pendekatan klasifikasi, iaitu pendekatan berasaskan piksel dan pendekatan berasaskan rantau menggunakan metod penakrifan rantau kulit secara eksplisit, parametric, dan tak-parametrik. Pengkelas kulit diuji dengan menggunakan set data ujian dan juga set data piawai; UChile dan TDSD bagi mengukur prestasi pengkelas. Prestasi pengkelas kulit diukur dengan menggunakan petunjuk *true positive* (TP) dan *false positive* (FP).

Dalam pendekatan klasifikasi berasaskan piksel, tiga metod dilaksanakan untuk permodelan taburan warna kulit; nisbah *RGB*, analisis diskriminasi lelurus (LDA),

dan rangkaian neural (NN) *back propagation*. Model nisbah *RGB* mewakili metod penakrifan rantau kulit secara eksplisit, manakala LDA dan NN mewakili metod parametrik dan tak-parametrik. Model nisbah RGB merupakan satu inovasi baru dalam metod penakrifan rantau kulit secara eksplisit. Model ini telah dibandingkan dengan model-model Kovac, Saleh, dan Swift. Hasil eksperimen menunjukkan bahawa model nisbah RGB adalah lebih baik kadar pengesanannya dibandingkan dengan model-model yang dinyatakan sebelum ini. Model nisbah RGB berupaya menggurangkan nilai FP yang terhasil daripada warna objek kemerah-merahan, dan juga berupaya mengesan warna kulit gelap dan kulit yang terlindung oleh bayang-bayang. Sementara itu, metod LDA dan NN digunakan bersama-sama dengan lapan model warna; model-model warna *RGB*, *HSV*, *YIQ*, *YCbCr*, *LUX*, *Opponent*, *CIE-Lab*, dan *RGB normalised* bagi membangunkan model taburan warna kulit. Hasil eksperimen menunjukkan bahawa model-model warna yang digunakan memberi prestasi yang baik menggunakan metod NN dibandingkan dengan metod LDA, kecuali model warna LUX. Hasil eksperimen juga menunjukkan bahawa model warna CIE-Lab memberi prestasi yang terbaik dalam membina pengkelas kulit menggunakan sama ada metod LDA atau metod NN.

Dalam pendekatan klasifikasi berasaskan rantau, tiga belas fetur tekstur Haralick telah digunakan bagi membangunkan model taburan warna kulit. Satu teknik baru telah diperkenalkan bagi mengira fetur tekstur berkenaan yang dikenali sebagai *colour mapping co-occurrence matrix* (CMCM). Terdapat empat CMCM yang telah dibangunkan pada pementaan warna yang berbeza; CMCM untuk [RGB], [RG], [RB], and [GB]. Tesis ini juga telah melaksanakan tiga jenis teknik permodelan dalam pendekatan klasifikasi berasaskan rantau; metod pentakrifan rantau kulit

secara eksplisit, parametrik, dan tak-parametrik. Model bendul kehomogenan telah diperkenalkan dalam metod penakrifan rantau kulit secara eksplisit. Model ini menunjukkan prestasi yang sangat baik dari segi kadar FP.

Metod-metod LDA dan NN telah dilaksanakan bersama-sama dengan CMCM untuk membangunkan pengkelas kulit. Empat CMCM telah digunakan dalam eksperimen; [RGB] CMCM pada orientasi (1, 0^{o}), (1, 45^{o}), (1, 90^{o}) dan (1, 135^{o}), [RG], [RB] dan [GB] CMCM pada orientasi (1, 0^{o}) dan (1, 45^{o}). Hasil eksperimen telah menunjukkan bahawa pengkelas kulit terhasil dengan [RGB] CMCM pada orientasi (1, 0^{o}) adalah terbaik kadar pengesanannya jika dibandingkan dengan CMCM yang sama pada orientasi yang berlainan dari segi nilai FP. Hasil eksperimen ini juga menunjukkan bahawa pengkelas terhasil dengan [RGB] CMCM pada orientasi (1, 90^{o}) tidak berupaya mengesan piksel kulit dan piksel bukan-kulit. Sementara itu, pengkelas terhasil dengan [RG] CMCM pada orientasi (1, 0^{o}) adalah terbaik kadar pengesanannya jika dibandingkan dengan [RB] CMCM dan [GB] CMCM pada orientasi (1, 0^{o}) dan (1, 45^{o}), masing-masing dari segi kadar FP, dan prestasinya hampir sama dengan pengkelas terhasil dengan menggunakan [RGB] CMCM pada orientasi (1, 0^{o}). Kesimpulannya, eksperimen ini menunjukkan bahawa pengkelas terhasil menggunakan metod NN adalah lebih baik jika dibandingkan dengan pengkelas terhasil dengan menggunakan metod LDA.