UNIVERSITI PUTRA MALAYSIA

PREDICTING SALIENCY EXISTENCE USING REDUCED SALIENT FEATURES BASED ON COMPACTNESS AND BOUNDARY CUES

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By

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

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November 2020

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Salient object detection is a process that tries to locate the most prominent region within the visual scene. Despite of hundreds of successful developed models, most of the models still fail to produce correct detection for background only image and this is due to the models' assumption that a salient object must at least exist in an image. As for the previous models for saliency prediction, the developed models require complex computation for feature extraction with large number of salient features. Therefore, there is a need to develop a model for predicting saliency existence as it is able to categorise the input images as salient or non-salient. This research presented a method that can anticipate the existence of a salient object in the input image retrieved from ASD and SOSB datasets based on the compactness and boundary cues. This basis of assumption was adopted given the fact that the compactness of a non-salient image is spatially distributed as referred to its boundary compared to the salient image. The image background is measured based on the boundary contrast and boundary spatial distribution within the spatial and the frequency domain. These measurements represent the salient features that were extracted based on statistical computations that act as the global saliency identification. In order to reduce the number of extracted features, the salient features were selected based on filter method through the saliency histogram. The selected salient features were trained, tested and compared on 3 learning algorithms which included generalised linear regression, Naïve Bayes, and Support Vector Machine. By using the proposed method, the accuracy of the prediction was achieved where a maximum of 91.5% was obtained while other measurements of specificity, precision and recall obtained more than 90% accuracy. The validation of the developed model was tested on the current salient object detection model to observe the performance implication detecting the salient object. The saliency existence prediction on the integrated model achieved 92.5% for accuracy with the sacrifice of execution time which increased by 12.3% as compared to the salient object detection model BCA. This research does not only contribute to the model

development but can also become an initial study focusing on saliency existence prediction that may have an impact on further model improvements in the future.

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

RAMALAN KEWUJUDAN TONJOLAN DENGAN MENGGUNAKAN PENGURANGAN FITUR TONJOLAN BERDASARKAN ISYARAT KEPADATAN DAN SEMPADAN

Oleh

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Pengesanan objek tonjol ialah suatu proses bagi menjejak kawasan yang menonjol pada suatu pandangan visual. Walaupun telah banyak model yang dibangunkan, kebanyakkan model yang ada masih gagal untuk memberikan keputusaan pengesanan yang betul pada imej latar belakang. Ini adalah disebabkan andaian pada model yang menganggap wajib wujud sekurang-kurangnya satu objek tonjol pada sesuatu imej. Dalam satu cabang bidang ini yang dipanggil ramalan ketonjolan, model-model yang dibangunkan memerlukan penghasilan fitur yang kompleks dan bilangan fitur yang banyak untuk disari. Oleh itu, terdapat keperluan untuk menghasilkan model yang dapat meramalkan kewujudan kawasan tonjolan bagi mengketogorikan input imej sebagai imej tonjol dan imej bukan-tonjol. Kajian ini memperkenalkan satu kaedah yang dapat meramal kewujudan satu objek tonjol pada sesuatu imej input yang diambi dari set data ASD dan SOSB berdasarkan isyarat sempadan dan kepadatan. Dasar andaian ini telah diambil kira melalui fakta yang menyatakan kepadatan pada imej bukan-tonjol adalah terserak pada ruangan dalam merujuk pada sempadan imej berbanding dengan imej yang mempunyai objek tonjol. Latar belakang imej diukur berdasarkan beza sempadan dan taburan ruang sempadan dalam domain ruang dan frekuansi. Ukuran ini mewakili fitur tonjolan yang disari berdasarkan pengiraan statistik yang bertindak sebagai fitur ketonjolan global. Bagi mengurangkan bilangan fitur yang disari, fitur dipilih berdasarkan teknik sarian dan fitur tonjolan yang terpilih dilatih, diuji dan dibandingkan pada 3 algoritma pembelajaran iaitu generalised linear regression, Naïve Bayes dan Support Vector Machine. Dengan menggunakan kaedah yang dicadangkan, 91.5% kejituan ramalan telah berjaya dicapai dan lain-lain ukuran seperti ketentuan dan kepersisan telah mencapai lebih dari 90%. Pengesahan model yang dibangunkan telah diuji pada model pengesanan objek tonjol yang terkini bagi menilai implikasi prestasi dalam mengesan objek tonjol. Ramalan kewujudan tonjolan pada model yang digandingkan telah mencapai 92.5% kejituan dengan

peningkatan waktu laksana sebanyak 12.3% dibandingkan dengan model pengesanan objek tonjol BCA. Kajian ini bukan sahaja memberi sumbangan dalam pembangunan model tetapi ia juga menjadi suatu kajian awal yang memberi penekanan pada ramalan kewujudan tonjolan yang mampu memberi impak bagi tujuan penambahbaikan lanjutan pada masa akan datang.

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

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LIST OF ABBREVIATIONS

AUC	Area under curve
BCA	Boundary component affinity
BCC	Boundary contrast compactness
BCCi	Imaginary boundary contrast compactness
BCCr	Real boundary contrast compactness
BSDC	Boundary spatial distribution compactness
BSDCi	Imaginary boundary spatial distribution compactness
BSDCr	Real boundary spatial distribution compactness
CC	Contrast compactness
DFT	Discrete Fourier transform
FN	False negative
FP	False positive
FPR	False positive rate
GoF	Goodness of fit
gLR	Generalised linear regression
HIR	Histogram intersection ratio
HVS	Human visual system
IQR	Inter-quantile range
LR	Linear regression
MAE	Mean absolute error
mBCC	Mean boundary contrast compactness
mBCCi	Mean imaginary boundary contrast compactness
mBCCr	Mean real boundary contrast compactness
mBSDC	Mean boundary spatial distribution compactness
mBSDCi	Mean imaginary boundary spatial distribution compactness
mBSDCr	Mean real boundary spatial distribution compactness
NB	Naïve Bayes
RGB	Red Green Blue

ROC	Receiver operating characteristic
ROI	Region of interest
S-BCA	Structured boundary component affinity
SDC	Spatial distribution compactness
SE	Standard error
SEP	Salient existence prediction
SOD	Salient object detection
SSE	Sum squared error
SSR	Sum squared regression
SVM	Support vector machine
sBCC	Standard deviation boundary contrast compactness
sBCCi	Standard deviation imaginary boundary contrast compactness
sBCCr	Standard deviation real boundary contrast compactness
sBSDC	Standard deviation boundary spatial distribution compactness
sBSDCi	Standard deviation imaginary boundary spatial distribution compactness
sBSDCr	Standard deviation real boundary spatial distribution compactness
TN	True negative
TNR	True negative rate
TP	True positive
TPR	True positive rate

CHAPTER 1

INTRODUCTION

1.1 Background

Human vision is so amazing where 80% of the information received in the human brain comes from the vision of the eyes. The multi-information that enters human eyes during the visualisation is used by the brain to understand and react to the human environment. The information is then compared to assign priority and subsequently filtered in a way that the important information quickly pop-out on the vision's context. Therefore, information processing in the human brain becomes more rapid and accurate, enabling human vision to focus on certain visual regions where other regions are put in lower preferences. This capability is referred to as visual attention in which it provides focus within the human visual region.

There are two mechanisms that influence human visual attention which are bottom-up attention and top-down attention. The bottom-up attention is fast and data-driven, focusing on visual features including colour, texture and orientation[1]. On the other hand, the knowledge based top-down attention is slower in which the human vision is concentrated on the visual region that is more likely to be the target attended scene [2]. It is a voluntary allocation of attention to certain features, objects, or regions in space [3].

This astonishing ability of humans in receiving, processing, and manipulating visual information is so incredible that researchers have been investing a lot of efforts in imitating this capability in the computer system. This is known as salient object detection (SOD) where a system tries to locate the most outstanding or prominent region in the visual scene. The integration of this mechanism into a system is able to provide benefits in that the processing time of the next semantic operation will be shortened by masking the unimportant information and focusing only on the prime region within the visual scene.

The SOD model has been applied in many applications such as object detection and segmentation [4], [5], image retargeting [6], [7], image compression [8]–[10], and image quality assessment [11]. The models have been successfully applied in many multi-discipline areas including multimedia [12], [13], medical [14], remote sensing [15], [16], and robotics [17], [18].

Generally, the process of salient object detection involves two steps which include detection of the salient object and segmentation of the exact salient region of the object. The output of the model is a saliency map where the salient object will be presented in a higher intensity compared to its surroundings. The main goal of the problem is to segment the most prominent region in the visual scene which is known as the foreground.

In the scope of computer vision, this field of study is used as the pre-attentive stage where the important region or pixels in the visual scene are highlighted in higher intensity, and the visual background diminished. The output of this saliency map is later used to apply further semantic process in any other specific application. Therefore, the overall processing time is reduced as the semantic process is only focused on the prominent region with lesser number of pixels involved compared to the traditional process that includes the entire pixel in the image.

As application of the SOD algorithm has been seen to offer benefits in terms of good detection with shorter processing time in various computer vision applications, it can be observed that thousands of models have been competitively proposed with the same aim of achieving the results of accurate detection in real time. However, the problem is far from being solved as no single model is able to produce accurate detection in all types of visual conditions. This research focused on analysing salient existence in input images and this is explained further in the next section.

1.2 Research motivation

The research begins with a group discussion that talked about the capability of an intelligent vehicle. With the advancement of sensing technologies, an intelligent vehicle is capable to offer multi-features that comprises of safety, cruising, navigating and many more components. Video camera is one of the sensing inputs used to give feedback about the vehicle's surroundings. A fast responsive system can be produced if the time taken to process the visual field is shorten, where the system only processes the important area and ignoring the less important information. This has become a triggering question that led to further study. After few readings, it was found that the related study that focuses on important region in the vision area and ignoring the background is SOD. Further reading in the field has emerged student's interest and thus it has been decided that the research wanted to set its focus in the scope of SOD where it believes can be beneficial for many areas of applications including the intelligent vehicle.

1.3 Problem statements

Based on detailed study of the literature in the area of SOD, there is an aspect that has been neglected by the community, and this aspect is salient existence analysis or also known as salient existence prediction (SEP). Very few studies have focused on this scope [19]–[21] even though the status of salient existence is essential to ensure that the detection system is able to locate the object only in an image that contains the salient object and ignore the non-salient image. The related problems for this research are complex saliency existence features, large numbers of features and few models developed to predict the saliency existence. The listed problems are mainly related to SEP model and the detailed explanation of the issues are presented in the next section.

1.3.1 Complex salient features

An early attempt to detect the salient object existence in thumbnail images has combined multiple object-level cues (pixel, regional and object-level cues) to produce the final feature vector [19]. The features were adopted from other benchmark models [22], [23] where learning method also need to be applied in order to identify the saliency features. On the other hand, one of a recent study that related to salient existence prediction has utilized the labelled training data from Image Net [24] obtained from the convolution neural network (CNN) to extract the image-level and region-level saliency features [21]. By examining both models, the extraction of saliency features required combination of multi-cues and learning method. Thus, it makes the process become complex and a good SEP model should be simple since SEP is a pre-attentive step before the following semantic process.

1.3.2 Large numbers of salient features

Great advancement in deep learning has led to this method being applied in saliency prediction and it has resulted in outstanding output detection [21], [25], [26]. Despite the accurate and precise detection, the application of the learning architecture requires large numbers of salient features, resulting in the increase of processing time. Thus, this might lead to impractical usage of deep learning in salient prediction since good salient object detection system must be carried out in real-time [27]. Liang *et al.* have also highlighted this issue in their study and they proceeded to consider reducing the number of saliency features into 48 components [28]. The listed features consist of low-level features, middle-level features, high-level features, centre prior computation, and 15 features on the combination of 13 bottom-up saliency models. However, this method requires multi-processes of computations and thus consumes higher processing time.

1.3.3 Few researches in SEP models development

The past decade has seen a tremendous performance in recent developed SOD models. However, most of the state-of-art models still fail to produce correct detection for non-salient images. An extensive study to identify the best SOD models has highlighted the issue and it occurs due to impractical assumption of models that assuming there exist at least one salient object in the input image [29]. This assumption is relatively unreliable as no dominant object should be detected on this type of images. A few images on datasets that contain texture and cluttered background were selected and tested on the most outstanding SOD models [30]–[32] and on a classical fixation prediction model [33]. The output of the saliency map can be referred to in Figure 1.1.

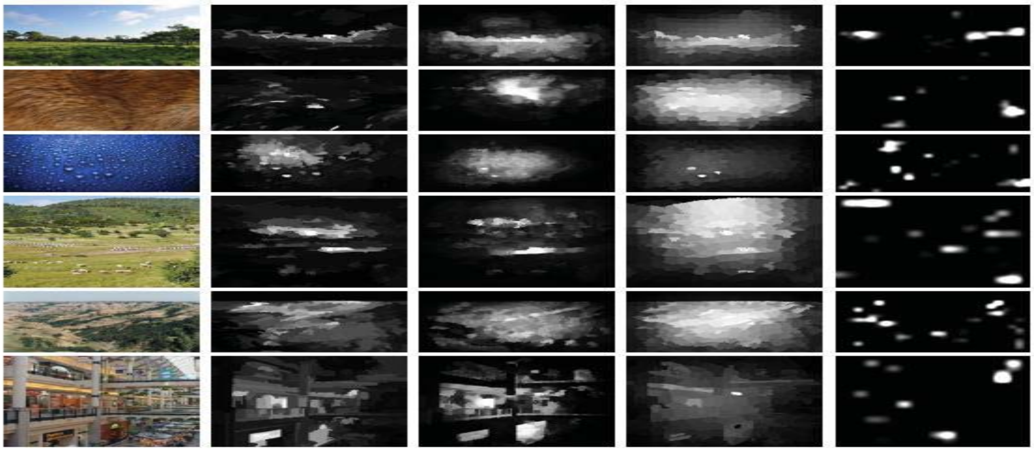

Figure 1.1 : The saliency map obtained on background only images that consist of texture and cluttered background when tested on the selected models [33]

It can be observed that the saliency map resulting from the models' computation still produced salient regions even on uniform image textures as shown in row 2 and row 3. It occurred because of the assumption that a salient object must exist, and the models thus tried to locate the prominent area in the input image. Based on the bottom-up visual attention, the contrast cue will always be included as part of the consideration in computing the saliency map. Therefore, it is expected that the region having higher contrast will have a higher tendency to be highlighted as the salient object. The study also agreed that the research in SEP has been neglected by the community since much works were focus on developing accurate and precise SOD models. As a result, there were only few studies that related with SEP [19]–[21].

A similar issue was highlighted in the most recent study by Jiang *et al.* where they tested the state-of-the-art models [30], [31], [34]–[36] on background only images (no salient object) [21]. Their study revealed the same results as most of the models still resulted in salient regions on the background only images. The results of the saliency map obtained by Jiang *et al.* are illustrated in Figure 1.2.

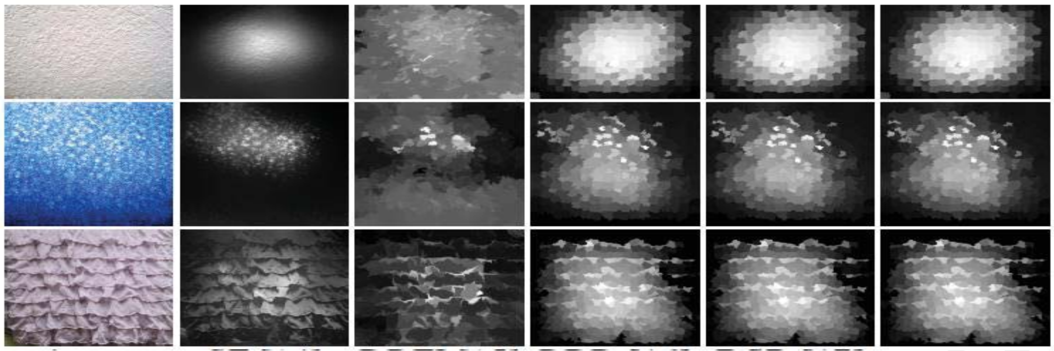

Figure 1.2 : Saliency map obtained by 5 state-of-the-art models on background only images. From left to right, input images, SF [37], DRFI [30], RBD [35], DSR [38] and MCDL [36]

From the saliency map obtained in Figure 1.4, it can be observed that the models still produced salient objects on the textured images even though some of the models have been integrated with the learning algorithm. This happened because of the models' assumption that there must exist at least one salient object in the image. In another study, Zhang *et al.* also agreed that knowing the existence of salient objects in images is important and they therefore extended their study to include counting of the detected salient object which is known as subitizing [20].

Based on these 3 aspects of highlighted issues, it is clear that there is a need to develop a SEP model that requires simple with less numbers of saliency features. Therefore, the focus of this research was on finding a solution to the problem based on several hypotheses that will be discussed in the following section.

1.4 Research hypothesis

The essential components in developing the SEP model include finding the characteristics that are able to differentiate images with salient and non-salient objects. In most salient object detection models, colour cue has been widely applied as images with salient objects usually contain regions with higher contrast compared to the rest of the image area. This is because high colour contrast is one of the fastest low-level features that is able to catch human vision to look on within the vision area. The salient region usually has higher contrast and is more compact with similar colour range compared to the image background [39]. As for the non-salient image (background only image), the colour contrast is distributed evenly across the entire image as this type of image contains similar range of colour difference. Thus, the colour compactness is also lower in the entire image.

In the SOD model by Zhang *et al.*, the boundary connectivity hypothesis was applied to measure the image background in order to produce the saliency map [35]. They made the assumption that the boundary of the image will always be the image background and thus comparing the regions of the image against the boundary of the image will make the image background and foreground distinguishable. It was measured based on the degree of connectivity of each region or patch in the image with the boundary region of the image. A higher degree of connectivity indicates that the possibility of the region being the image background is greater.

Inspired by Zhang *et al.*'s study, it is believed that by computing colour compactness against the image boundary, distinct features to differentiate the salient and non-salient image can be obtained. In order to obtain an immediate global feature, simple statistical analysis can be used as an effective measurement to produce a single value for classifying salient and non-salient images. Therefore, these 3 hypotheses, namely colour compactness, boundary analysis, and statistical analysis were utilised in this study to develop the salient existence prediction model.

1.5 Main research question

How can the compactness and boundary cues be integrated to produce relevant features in learning method to predict saliency existence for efficient salient object detection on images?

1.5.1 Research questions

Three research questions can be used as the main scope of this research, and these are:

i. What are the features that can be extracted based on compactness and boundary cues to produce salient features that are able to distinguish between salient and non-salient images?

ii. How to reduce the number of extracted features to become as the most relevant features for the SEP model?

iii. What is the most effective supervised learning algorithm that can be used on the selected features for classifying the images with into either salient or non-salient objects?

1.6 Research objectives

Based on the research questions formulated, the research objectives were then constructed, and they are listed as follows:

i. To determine the salient features that able to distinguish between salient and non-salient images based on compactness and boundary cues by applying non-complex computation.

ii. To identify the most significant salient features in characterizing the salient and non-salient images by reducing the extracted salient features.

iii. To develop a model that able to predict the saliency existence in input images by utilizing the selected salient features on learning algorithm.

1.7 Scope of work

In considering developing a fundamental study for saliency existence, the scope of work that has been bounded in the research are listed as follows:

i. There were two type of input images involved in the research which were image with salient object (salient image) from the ASD [40] dataset and image without salient object or background only image (non-salient image) from the SOSB [21] datasets. Both datasets are publicly available online.

ii. The images selected for salient image were simple which contained single salient object with clear and uncluttered background. On the other hand, the images that were uniform background contrast were selected for the non-salient images.

1.8 Thesis organisation

This thesis is organised and presented in 5 chapters. Chapter 1 explains the background of SOD and the problems identified based on literature review in the area of study. The implementation of the research was guided by the constructed objectives in which the research outcomes could be used as the items to clarify and provide explanation for the research questions. Therefore, the research was bounded by the scope delineated in the research questions.

The development of the SEP model was carried out based on literature review in the field of SOD in combination with several other related areas that included the scope of salient prediction and supervised learning. These studies are explained in-depth in Chapter 2. Additionally, at the end of the chapter, a summary in the form of a table that highlights the current salient prediction models and the related techniques or approaches that have been applied is presented.

Chapter 3 is about the establishment of the SEP model, including the theoretical understanding involved in constructing, extracting, and selecting the relevant features. The model development comprised 3 main phases which were *Phase 1: Feature development phase; Phase 2: Training and testing of classifier;* and *Phase 3: Application of the testing phase*. The detailed description of the model development is also presented in this chapter.

In finalising the SEP algorithm, several experiments and data analyses had to be performed using the available datasets, and these are all explained in Chapter 4. This chapter also provides the discussion of the results of the evaluation obtained from the experiments together with a few failure cases. Additionally, the final algorithm of the constructed model is also presented at the end of this chapter.

The final chapter or Chapter 5 presents the conclusion of the research outcome and the knowledge contribution of this research through the development of the SEP model. Chapter 5 ends with a few recommendations that include the improvements that can be made within the algorithm, the construction of the data sets and testing in other computer vision applications.

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