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Small object detection in forward-looking infrared images with sea clutter using context-driven Bayesian saliency model

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HIGHLIGHTS

- Small object detection in FLIR images with sea clutter is studied in this paper.
- A context-driven Bayesian saliency detection (CBSD) model is proposed.
- CBSD exploits the horizon line as context to reduce detection ambiguity.
- The scale variance problem is also taken into consideration in CBSD.

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ABSTRACT

There are two common challenges for small object detection in forward-looking infrared (FLIR) images with sea clutter, namely, detection ambiguity and scale variance. This paper presents a context-driven Bayesian saliency model to deal with these two issues. By inspecting the camera geometry of the FLIR imaging under the background of sea and sky, we observed that there exists dependency relationship between the locations and scales at which objects may occur, and the context which is defined to be the location of horizon line. Based on this observation, we propose to incorporate contextual information into the basic bottom-up saliency computation, and a unified Bayesian model is developed to achieve this goal. The proposed model is generic and can be potentially applied to other circumstances where context is available for facilitating object detection. Experimental results have demonstrated the effectiveness of our method.

1. Introduction

This paper is concerned with the object detection problem in a specific kind of images, i.e., forward-looking infrared (FLIR) images with sea clutter and sky as the background, which can find its application in maritime surveillance [1], unmanned aerial vehicle [2] and so on.

Several practical factors make this task more challenging than a typical object detection problem. The first one is the so-called detection ambiguity issue. In the aforementioned application circumstances, it is mostly required to detect objects at the early stage upon their emergence into the view of the image, which by this time are distant and thus appear to be small and dim. Also, the image usually contains complicated background, consisting of sea clutter and sometimes clouds, which immerse the foreground objects to be detected. As a result, it is difficult to distinguish foreground objects from distractors, leading to significant detection ambiguity as well as difficulties for other tasks like tracking or matching [3,4]. The second challenge lies in object scale variance. Generally, the scale used to detect an object should match its true size in the image, otherwise effectiveness may be largely degraded. In the applications of our concern, as objects move from far to near, their scales appeared in the image are changing. Also, an image may contain multiple objects of different physical scales to be detected. Therefore, it is desired an algorithm can automatically cope with the scale variance problem, rather than assuming a fixed scale in advance.

Small and dim object detection has been intensively studied in the literature. Many early works were focused on designing suitable filters to enhance foreground objects while suppressing background distractors, like median subtraction filter [5], matched filter [6], max-mean/max-median filter [7], top-hat filter [8],

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frequency-domain filter [9], etc. Some other approaches are based on regression models [10,11], assuming a background model and then estimating the model by parametric or non-parametric regression. The works in [12,13] exploit the center-surround mechanism of biological vision to derive a method for small object detection. In [14], Gao et al. used the sparse and low-rank matrix decomposition to separate the image into a foreground part and a background part. The authors in [15] took into consideration both foreground enhancement and background suppression simultaneously by optimizing the signal-to-clutter ratio, as well as the varying scale problem by scale-space analysis. In spite of their effectiveness in certain situations, these approaches either show limited performance in case of heavy background clutter, or assume object scales are known beforehand.

Some prior works also utilized the information of horizon line to improve object detection under sea-sky background [16–19]. However, these works straightforwardly use horizon line to restrict the candidate locations where objects may occur in a hard-decision manner, that is, totally ignoring the locations outside the candidate region. This is at risk of error since the detection of horizon line may be inaccurate in practice, particularly in case of complicated background like sea clutter.

In this paper, we propose a novel method to deal with the problems of detection ambiguity and scale variance for small object detection in FLIR images with sea clutter. We follow the typical paradigm of salient object detection, that is, first calculating a saliency map from the given image, and then thresholding the saliency map to obtain the object detection result. By defining saliency from the Bayesian perspective, the key insight of this work is that, inspired by the success of context modeling for computer vision tasks [20–28], we incorporate contextual information into the basic bottom-up saliency computation, leading to a context-driven Bayesian saliency detection (CBSD) model. More specifically, we take as context the horizon line, *i.e.*, the division line between the sky and the sea area, which commonly exists in images with sea clutter and is relatively easy to detect. This is because we observed that there exists dependency relationship between the locations and scales of objects and the location of the context, which is intrinsically determined by the camera geometry of FLIR imaging, and such relationship can be used to solve the detection ambiguity and the scale variance problems. We therefore integrate bottom-up saliency cues, object locations and scales, context and the dependency relationship between them within a unified Bayesian model and derive an approach for saliency computation by Bayesian inference.

In summary, the contributions of this paper are as follows:

- We propose a context-driven Bayesian model to define saliency, which incorporates contextual influences into the basic bottom-up saliency computation, based on the relationship between context and object locations and scales.
- Based on this model, we develop an effective approach for small object detection in FLIR images with sea clutters, which can cope with the problems of detection ambiguity and scale change.

2. Motivation

In traditional bottom-up saliency models [29–31,28], saliency is usually computed over each location within the image and at each scale identically, considering objects are equally likely to appear at all the locations and the scales. This is reasonable in the generic situation when no prior knowledge is available. However, in our particular case of FLIR images with sea clutter, given the presence of context (*i.e.*, the horizon line), it is no longer reasonable to treat all the locations and scales equally. This is because, in such a circumstance, there exists dependency relationship between the context and the locations and scales at which salient objects are possible to occur. More precisely, as illustrated in Fig. 1, the dependency relationship can be stated as that, locations near the horizon line are more likely to contain salient objects than locations that are not, and also, objects are more likely to appear as small scales when located close to the horizon line.

In the following, we justify the aforementioned dependency relationship from the perspective of FLIR imaging geometry. As illustrated by Fig. 2(a) and (b), in a FLIR image with sea and sky in the background, the horizon line stems from the curvature of the Earth. By inspecting the geometry in Fig. 2(c), one can find that, the quantitative relationship between the distance d in the physical world and the distance y in the image plane is given by

$$d = D - h\tan\left(\arctan\frac{D}{h} - ky\right), \quad y \geqslant 0, \tag{1}$$

where $h = |CG|$ is the camera height from the ground (the Earth surface), k is a factor determined by the view angle of the camera and the pixel resolution of the image, and $D = |GH|$ is the ground distance between the camera and the horizon line in the physical world, which can be approximated by the relationship that $\frac{|CG|}{|GH|} = \frac{|CH|}{|OH|}$ and $|CH| \approx |GH|$, resulting in $D = \sqrt{2hR}$ with $R = |OH|$ representing the radius of the Earth. Note that we only consider $y \geqslant 0$, *i.e.*, the sea part of the image, in the following.

To get intuition about the quantitative relationship given by Eq. (1), let us give an example as plotted in Fig. 2(d), where we set h as 10 meters, the view angle of the camera as $1/3$ rads and the pixel resolution of the image as 512×512. As can be seen, a distance of one pixel near the horizon line in the image plane may correspond to a distance of several thousands of meters in the physical world, while a distance of one pixel far from the horizon line may correspond to only tens of meters, in another word, in the image space, locations close to the horizon line have larger spatial resolutions than locations that are far from the horizon line.

The observation implies two facts: First, supposing the objects of interest are equally likely to occur at all locations in the physical world within the camera view, they will be more likely to reside near the horizon line in the image space, which we term as *context-driven location prior*. Second, a physical object of given size will appear to be smaller when it occurs near the horizon line in the image space, and vice versa, which we refer to as *context-driven scale prior*. Our idea is to exploit these two priors to facilitate salient object detection, and for this purpose a Bayesian model is proposed as described below.

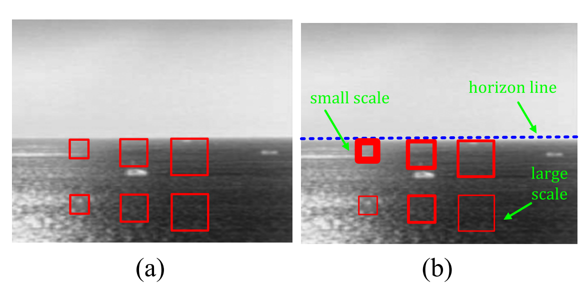

Fig. 1. Illustration of the motivation of this work. The blue dot line represents the horizon line (context), the rectangle size stands for object scale (smaller rectangles for smaller object scales), and the line thickness of the rectangles stands for the prior probability that salient objects will occur at the particular location and scale (thicker lines for higher probability). (a) Traditionally all the locations and scales are considered equally likely to be salient a priori, while (b) in this work locations near the horizon line are considered more likely to contain salient objects than locations that are not, and objects are more likely to appear as small scales when located close to the horizon line, and vice versa. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)