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A new technique for detecting colored macro plastic debris on beaches using webcam images and CIELUV

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ABSTRACT

We have developed a technique for detecting the pixels of colored macro plastic debris (plastic pixels) using photographs taken by a webcam installed on Sodenohama beach, Tobishima Island, Japan. The technique involves generating color references using a uniform color space (CIELUV) to detect plastic pixels and removing misdetected pixels by applying a composite image method. This technique demonstrated superior performance in terms of detecting plastic pixels of various colors compared to the previous method which used the lightness values in the CIELUV color space. We also obtained a 10-month time series of the quantity of plastic debris by combining a projective transformation with this technique. By sequential monitoring of plastic debris quantity using webcams, it is possible to clean up beaches systematically, to clarify the transportation processes of plastic debris in oceans and coastal seas and to estimate accumulation rates on beaches.

1. Introduction

Global production of plastics increased from 1.7 Mt/yr in 1950–265 Mt/yr in 2010 (Plastics Europe, 2011). In line with this increase, plastic rubbish has accumulated in oceans and along coasts around the world (Barnes et al., 2009). This is one of the most serious problems affecting the global marine environment (Derraik, 2002). Most plastic debris originates from land-based sources and is transported long distances by ocean currents. During this process, the plastics except special plastics (e.g., biodegradable plastics) slowly fragment into macro-, meso- or micro-debris by photodegradation, oxidation and mechanical weathering (Barnes et al., 2009). Fragmentary plastics have been found in the stomachs of marine animals (Boerger et al., 2010; Moser and Lee, 1992; Shaw and Day, 1994; Van Franeker et al., 2011). In addition, there is much speculation that, if ingested, plastic has the potential to transfer toxic substances to the food chain (Teuten et al., 2009). To assess the deleterious effect of plastic debris on marine ecosystems, it is important to identify its sources, outflows, transportation routes and transportation fluxes (i.e., the processes by which plastic debris is transported), and to estimate the accumulation rates of plastic debris along the shoreline. To determine the transportation process and the accumulation rates of plastic debris, it is necessary to conduct continuous beach surveys at multiple sites simultaneously and to grasp the variations in amount of plastic debris at each site.

Numerous previous studies have investigated the amount, primary materials and types of beach litter (Sheavly, 2007; Ryan et al., 2009; Seino et al., 2009; Ribic et al., 2010). These studies are mostly based on in situ beach surveys conducted at monthly or greater than monthly timescales. Kako et al. (2010) recently established a system for the sequential monitoring of beach litter using webcams placed on Ookushi beach on the Goto Islands, Japan, and computed the temporal variability in the amount of beach litter over a period of one and a half years. They considered the covered area as an index of the amount of beach litter and computed the covered area by counting the photograph pixels that had higher lightness values than the established threshold value. In their study, the amount of beach litter generally fluctuated on a monthly or less than monthly timescale. It would be difficult to manually monitor the amount of beach litter on this timescale at multiple sites due to the personnel and cost required; however, webcams could be used to monitor multiple sites remotely and simultaneously, with low operating and labor costs.

Kako et al. (2010) applied the lightness value to detect photograph pixels of plastic debris (hereafter referred to as "plastic pixels") because of the prevalence of white polystyrene buoys in the beach litter on Ookushi beach. In the previous study, plastic pixels with light colors (e.g., white polystyrene) were detected, but plastic pixels with dark colors (e.g., blue or red plastics) were not detected. Generally, the plastic debris on beaches consists of both

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light and dark colors. The present study describes a method for detecting plastic pixels of any color and computing the beach area covered with plastic debris using photographs taken by a webcam installed on Sodenohama beach, Tobishima Island, Japan.

2. Materials and methods

2.1. Webcam monitoring system

The webcam was installed on Sodenohama beach, Tobishima Island, Japan (Fig. 1a and b). The webcam system consists of a webcam (IP7361, Vivotek), two solar panels (DC080-12, Denryo), two storage batteries (DC-31, ACDelco), a solar charge controller (SS-20L, Denryo), a timer (H2F-31, Omron), a mobile router (DCR-G54/U, I-O Data Device) and a mobile card (L-05A, LG Electronics). Electric power to operate the system is charged by the two storage batteries using the two solar panels. The webcam is controlled by the timer and operates every 2 h from 7:00 to 15:00 (JST) (five times every day). Five photographs are taken at intervals of 3 min during each operation, resulting in 25 photographs daily. The photographs are transmitted to our laboratory via the Internet. They are also backed up on an SDHC card installed in the webcam.

2.2. Generation of color references to detect plastic pixels

Generally, plastic debris in photographs can be recognized from the shape or color by human perception. However, shape recognition is difficult to achieve in image processing since the shape of the plastic debris depends on its orientation to the webcam. Also, beached plastic debris has fragmented into smaller debris with various shapes by the chemical and/or mechanical weathering. Thus, we attempted to detect plastic pixels by image processing using the color. The color of plastic debris changes in a specific range of a certain color space due to the amount and angle of sunlight (Fig. 2a). To detect plastic pixels in images, the particular color range of the plastic debris in the color space, that is, a color reference, must be defined, and then each pixel can be identified as a plastic pixel or not according to its position in the color space. In order to define the color reference, color difference is used. The color difference is measured as the Euclidean distance between two colorimetric values in the color space. The Commission Internationale de l'Éclairage (CIE) recommended the CIELUV color space, which attempts to achieve perceptual uniformity, to measure the color difference (CIE, 1986). The CIELUV color space is a three-dimensional color space having lightness L^*, extent of redness–greenness u^*, and extent of yellowness–blueness v^* (CIELUV value). In this study, the CIELUV color space is used as the color space to define the color reference.

The original photographs are in JPEG format, and each pixel has a red (R), green (G) and blue (B) value (RGB value). However, RGB color space is not perceptually uniform. The RGB value of each pixel in the photographs can be converted to the CIELUV value (L^*, u^* and v^*) (Fairchild, 2005). The color references are generated using the original photographs taken during certain periods. These periods are determined by considering the condition that most of the plastic debris is not moved by the winds and/or waves during the period. The images taken during the five periods (p1–p5) from November 2010 to May 2011 were used to generate the color references in this study (Table 1). At least one plastic item is selected for each color from images taken during each period. Because of the heterogeneous distribution of the CIELUV values on each item, we select 50 pixels as color-sample points from among the pixels of each item by human perception.

The CIELUV values for each color, to which the RGB values of sample pixels are converted, are dispersed on three coordinates (*U*–*L*, *V*–*L* and *U*–*V*) in the CIELUV color space (Fig. 2). Basically, the distribution of the CIELUV values is elongated in a particular direction due to the variability in the amount and angle of sunlight for each period. The distribution on each coordinate is approximated as an ellipse. The center of the ellipse is the average CIELUV value (hereafter, the color of the average CIELUV value is referred to as the "average color") (star in Fig. 2a). The length of the major axis of three ellipses represents twice the standard deviation of the color difference from the average CIELUV value in a certain direction. The standard deviation is obtained by a solution of an eigenvalue problem on a variance–covariance matrix, and is the square root of the eigenvalue of the first mode. The direction of the major axis

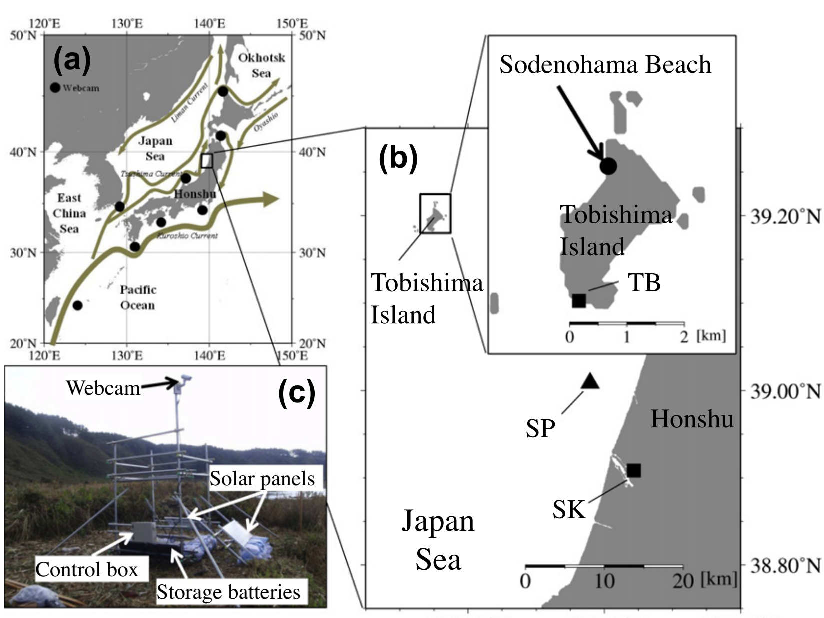

Fig. 1. (a) Map showing the locations of the installed webcams (solid circles) and sea currents around Japan, and (b) enlarged map of the area around Tobishima Island. Map (b) indicates the location of the webcam placed on Sodenohama beach on Tobishima Island, the meteorological observatories (SK and TB) of the Japan Meteorological Agency (solid squares) and the seabed wave gauges (SP) of the Port and Airport Research Institute (solid triangles). (c) Photograph of the webcam system.